Appendix B

Physical Property Tables

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Table B.1 Selected Physical Property Data[a]

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f°)$[h,j] kJ/mol	$(\Delta\hat{H}_c°)$[i,j] kJ/mol
Acetaldehyde	CH_3CHO	44.05	$0.783^{18°}$	−123.7	—	20.2	25.1	461.0	—	−166.2(g)	−1192.4(g)
Acetic acid	CH_3COOH	60.05	1.049	16.6	12.09	118.2	24.39	594.8	57.1	−486.18(l)	−871.69(l)
Acetone	C_3H_6O	58.08	0.791	−95.0	5.69	56.0	30.2	508.0	47.0	−438.15(g) −248.2(l)	−919.73(g) −1785.7(l)
Acetylene	C_2H_2	26.04	—	—	—	−81.5	17.6	309.5	61.6	−216.7(g) +226.75(g)	−1821.4(g) −1299.6(g)
Ammonia	NH_3	17.03	—	−77.8	5.653	−33.43	23.351	405.5	111.3	−67.20(l) −46.19(g)	−382.58(g)
Ammonium hydroxide	NH_4OH	35.03	—	—	—	—	—	—	—	−366.48(aq)	—
Ammonium nitrate	NH_4NO_3	80.05	$1.725^{25°}$	169.6	5.4		Decomposes at 210°C			−365.14(c) −399.36(aq)	—
Ammonium sulfate	$(NH_4)_2SO_4$	132.14	1.769	513	—		Decomposes at 513°C after melting			−1179.3(c) −1173.1(aq)	
Aniline	C_6H_7N	93.12	1.022	−6.3	—	184.2	—	699	52.4	—	—
Benzaldehyde	C_6H_5CHO	106.12	1.046	−26.0	—	179.0	38.40	—	—	−88.83(l) −40.04(g)	−3520.0(l) —
Benzene	C_6H_6	78.11	0.879	5.53	9.837	80.10	30.765	562.6	48.6	+48.66(l) +82.93(g)	−3267.6(l) −3301.5(g)
Benzoic acid	$C_7H_6O_2$	122.12	$1.266^{15°}$	122.2	—	249.8	—	—	—	—	−3226.7(g)
Benzyl alcohol	C_7H_8O	108.13	1.045	−15.4	—	205.2	—	—	—	—	−3741.8(l)
Bromine	Br_2	159.83	3.119	−7.4	10.8	58.6	31.0	584	102	0(l)	—
1,2-Butadiene	C_4H_6	54.09	—	−136.5	—	10.1	—	446	—	—	—
1,3-Butadiene	C_4H_6	54.09	—	−109.1	—	−4.6	—	425	42.7	—	—
n-Butane	C_4H_{10}	58.12	—	−138.3	4.661	−0.6	22.305	425.17	37.47	−147.0(l) −124.7(g)	−2855.6(l) −2878.5(g)
Isobutane	C_4H_{10}	58.12	—	−159.6	4.540	−11.73	21.292	408.1	36.0	−158.4(l) −134.5(g)	−2849.0(l) −2868.8(g)
1-Butene	C_4H_8	56.10	—	−185.3	3.8480	−6.25	21.916	419.6	39.7	+1.17(g)	−2718.6(g)
Calcium carbide	CaC_2	64.10	$2.22^{18°}$	2300	—	—	—	—	—	−62.76(c)	—
Calcium carbonate	$CaCO_3$	100.09	2.93			Decomposes at 825°C				−1206.9(c)	—
Calcium chloride	$CaCl_2$	110.99	$2.152^{15°}$	782	28.37	>1600	—	—	—	−794.96(c)	—

Calcium hydroxide	$Ca(OH)_2$	74.10	2.24			($-H_2O$ at 580°C)				−986.59(c)	—
Calcium oxide	CaO	56.08	3.32	2570	50	2850	—	—	—	−635.6(c)	—
Calcium phosphate	$Ca_3(PO_4)_2$	310.19	3.14	1670	—	—	—	—	—	−4138(c)	—
Calcium silicate	$CaSiO_3$	116.17	2.915	1530	48.62	—	—	—	—	−1584(c)	—
Calcium sulfate	$CaSO_4$	136.15	2.96	—	—	—	—	—	—	−1432.7(c) −1450.4(aq)	—
Calcium sulfate (gypsum)	$CaSO_4 \cdot 2H_2O$	172.18	2.32		($-1.5\ H_2O$ at 128°C)		—	—	—	−2021(c)	—
Carbon (graphite)	C	12.010	2.26	3600	46.0	4200	—	—	—	0(c)	−393.51(c)
Carbon dioxide	CO_2	44.01	—	−56.6 at 5.2 atm	8.33	(Sublimes at −78°C)		304.2	72.9	−412.9(l) −393.5(g)	— —
Carbon disulfide	CS_2	76.14	$1.261^{22°/20°}$	−112.1	4.39	46.25	26.8	552.0	78.0	+87.9(l) +115.3(g)	−1075.2(l) 1102.6(g)
Carbon monoxide	CO	28.01	—	−205.1	0.837	−191.5	6.042	133.0	34.5	−110.52(g)	−282.99(g)
Carbon tetrachloride	CCl_4	153.84	1.595	−22.9	2.51	76.7	30.0	556.4	45.0	−139.5(l) −106.7(g)	−352.2(l) −385.0(g)
Chlorine	Cl_2	70.91	—	−101.00	6.406	−34.06	20.4	417.0	76.1	0(g)	—
Chlorobenzene	C_6H_5Cl	112.56	1.107	−45	—	132.10	36.5	632.4	44.6	—	—
Chloroethane	C_2H_5Cl	See ethyl chloride									

[a]Adapted in part from D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, ©1974, Tables D.1 and F.1. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.

[b]Melting point at 1 atm.

[c]Heat of fusion at T_m and 1 atm.

[d]Boiling point at 1 atm.

[e]Heat of vaporization at T_b and 1 atm.

[f]Critical temperature.

[g]Critical pressure.

[h]Heat of formation at 25°C and 1 atm.

[i]Heat of combustion at 25°C and 1 atm. Standard states of products are $CO_2(g)$, $H_2O(l)$, $SO_2(g)$, HCl(aq), and $N_2(g)$. To calculate $\Delta\hat{H}_c^\circ$ with $H_2O(g)$ as a product, add $44.01n_w$ to the tabulated value, where n_w = moles H_2O formed/mole fuel burned.

[j]To convert $\Delta\hat{H}$ to kcal/mol, divide given value by 4.184; to convert to Btu/lb-mole, multiply by 430.28.

(*continued*)

Table B.1 (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f°)$[h,j] kJ/mol	$(\Delta\hat{H}_c°)$[i,j] kJ/mol
Chloroform	$CHCl_3$	119.39	1.489	−63.7	—	61.0		536.0	54.0	−131.8(l)	−373(l)
Copper	Cu	63.54	8.92	1083	13.01	2595	304.6	—		0(c)	—
Cupric sulfate	$CuSO_4$	159.61	$3.606^{15°}$			Decomposes > 600°C				−769.9(c)	—
Cyclohexane	C_6H_{12}	84.16	0.779	6.7	2.677	80.7	30.1	553.7	40.4	−843.1(aq) −156.2(l)	−3919.9(l)
Cyclopentane	C_5H_{10}	70.13	0.745	−93.4	0.609	49.3	27.30	511.8	44.55	−123.1(g) −105.9(l)	−3953.0(g) −3290.9(l)
n-Decane	$C_{10}H_{22}$	142.28	0.730	−29.9	—	173.8	—	619.0	20.8	−77.2(g) −249.7(l)	−3319.5(g) −6778.3(l)
Diethyl ether	$(C_2H_5)_2O$	74.12	$0.708^{25°}$	−116.3	7.30	34.6	26.05	467	35.6	— −272.8(l)	−6829.7(g) −2726.7(l)
Ethane	C_2H_6	30.07	—	−183.3	2.859	−88.6	14.72	305.4	48.2	−84.67(g)	−1559.9(g)
Ethyl acetate	$C_4H_8O_2$	88.10	0.901	−83.8	—	77.0	—	523.1	37.8	−463.2(l) −426.8(g)	−2246.4(l) —
Ethyl alcohol (Ethanol)	C_2H_5OH	46.07	0.789	−114.6	5.021	78.5	38.58	516.3	63.0	−277.63(l) −235.31(g)	−1366.91(l) −1409.25(g)
Ethyl benzene	C_8H_{10}	106.16	0.867	−94.67	9.163	136.2	35.98	619.7	37.0	−12.46(l) +29.79(g)	−4564.9(l) −4607.1(g)
Ethyl bromide	C_2H_5Br	108.98	1.460	−119.1	—	38.2	—	504	61.5	−54.4(g)	—
Ethyl chloride	C_2H_5Cl	64.52	$0.903^{15°}$	−138.3	4.452	13.1	24.7	460.4	52.0	−105.0(g)	—
3-Ethyl hexane	C_8H_{18}	114.22	0.717	—	—	118.5	34.27	567.0	26.4	−250.5(l) −210.9(g)	−5407.1(l) −5509.8(g)
Ethylene	C_2H_4	28.05	—	−169.2	3.350	−103.7	13.54	283.1	50.5	+52.28(g)	−1410.99(g)
Ethylene glycol	$C_2H_6O_2$	62.07	$1.113^{19°}$	−13	11.23	197.2	56.9	—	—	−451.5(l) −387.1(g)	−1179.5(l) —
Ferric oxide	Fe_2O_3	159.70	5.12			Decomposes at 1560°C				−822.2(c)	
Ferrous oxide	FeO	71.85	5.7	—	—	—	—	—	—	−266.5(c)	—
Ferrous sulfide	FeS	87.92	4.84	1193	—	—	—	—	—	−95.1(c)	—
Formaldehyde	H_2CO	30.03	$0.815^{-20°}$	−92	—	−19.3	24.48	—	—	−115.90(g)	−563.46(g)
Formic acid	CH_2O_2	46.03	1.220	8.30	12.68	100.5	22.25	—	—	−409.2(l) −362.6(g)	−262.8(l) —
Glycerol	$C_3H_8O_3$	92.09	$1.260^{50°}$	18.20	18.30	290.0	—	—	—	−665.9(l)	−1661.1(l)
Helium	He	4.00	—	−269.7	0.02	−268.9	0.084	5.26	2.26	0(g)	—

n-Heptane	C_7H_{16}	100.20	0.684	−90.59	14.03	98.43	31.69	540.2	27.0	−224.4(l) −187.8(g)	−4816.9(l) −4853.5(g)
n-Hexane	C_6H_{14}	86.17	0.659	−95.32	13.03	68.74	28.85	507.9	29.9	−198.8(l) −167.2(g)	−4163.1(l) −4194.8(g)
Hydrogen	H_2	2.016	—	−259.19	0.12	−252.76	0.904	33.3	12.8	0(g)	−285.84(g)
Hydrogen bromide	HBr	80.92	—	−86	—	−67	—	—	—	−36.23(g)	—
Hydrogen chloride	HCl	36.47	—	−114.2	1.99	−85.0	16.1	324.6	81.5	−92.31(g)	—
Hydrogen cyanide	HCN	27.03	—	−14	—	26	—	—	—	+130.54(g)	—
Hydrogen fluoride	HF	20.0	—	−83	—	20	—	503.2	—	−268.6(g) −316.9(aq, 200)	— —
Hydrogen sulfide	H_2S	34.08	—	−85.5	2.38	−60.3	18.67	373.6	88.9	−19.96(g)	−562.59(g)
Iodine	I_2	253.8	4.93	113.3	—	184.2	—	826.0	—	0(c)	—
Iron	Fe	55.85	7.7	1535	15.1	2800	354.0	—	—	0(c)	—
Lead	Pb	207.21	$11.337^{20°/20°}$	327.4	5.10	1750	179.9	—		0(c)	—
Lead oxide	PbO	223.21	9.5	886	11.7	1472	213	—	—	−219.2(c)	—
Magnesium	Mg	24.32	1.74	650	9.2	1120	131.8	—	—	0(c)	—
Magnesium chloride	$MgCl_2$	95.23	$2.325^{25°}$	714	43.1	1418	136.8	—	—	−641.8(c)	—
Magnesium hydroxide	$Mg(OH)_2$	58.34	2.4		Decomposes at 350°C			—			—
Magnesium oxide	MgO	40.32	3.65	2900	77.4	3600	—	—	—	−601.8(c)	—
Mercury	Hg	200.61	13.546	−38.87	—	−356.9	—	—	—	0(c)	—
Methane	CH_4	16.04	—	−182.5	0.94	−161.5	8.179	190.70	45.8	−74.85(g)	−890.36(g)
Methyl acetate	$C_3H_6O_2$	74.08	0.933	−98.9	—	57.1	—	506.7	46.30	−409.4(l)	−1595(l)
Methyl alcohol (Methanol)	CH_3OH	32.04	0.792	−97.9	3.167	64.7	35.27	513.20	78.50	−238.6(l) −201.2(g)	726.6(l) −764.0(g)
Methyl amine	CH_5N	31.06	$0.699^{-11°}$	−92.7	—	−6.9	—	429.9	73.60	−28.0(g)	−1071.5(l)
Methyl chloride	CH_3Cl	50.49	—	−97.9	—	−24	—	416.1	65.80	−81.92(g)	—

(*continued*)

Table B.1 (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f°)$[h,j] kJ/mol	$(\Delta\hat{H}_c°)$[i,j] kJ/mol
Methyl ethyl ketone	C_4H_8O	72.10	0.805	−87.1	—	78.2	32.0	—	—	—	−2436(l)
Naphthalene	$C_{10}H_8$	128.16	1.145	80.0	—	217.8	—	—	—	—	−5157(g)
Nickel	Ni	58.69	8.90	1452	—	2900	—	—	—	0(c)	—
Nitric acid	HNO_3	63.02	1.502	−41.6	10.47	86	30.30	—	—	−173.23(l)	—
										−206.57(aq)	
Nitrobenzene	$C_6H_5O_2N$	123.11	1.203	5.5	—	210.7	—	—	—	—	−3092.8(l)
Nitrogen	N_2	28.02	—	−210.0	0.720	−195.8	5.577	126.20	33.5	0(g)	—
Nitrogen dioxide	NO_2	46.01	—	−9.3	7.335	21.3	14.73	431.0	100.0	+33.8(g)	—
Nitric oxide	NO	30.01	—	−163.6	2.301	−151.8	13.78	179.20	65.0	+90.37(g)	—
Nitrogen pentoxide	N_2O_5	108.02	$1.63^{18°}$	30	—	47	—	—	—	—	—
Nitrogen tetraoxide	N_2O_4	92.0	1.448	−9.5	—	21.1	—	431.0	99.0	+9.3(g)	—
Nitrous oxide	N_2O	44.02	$1.226^{-89°}$	−91.1	—	−88.8	—	309.5	71.70	+81.5(g)	—
n-Nonane	C_9H_{20}	128.25	0.718	−53.8	—	150.6	—	595	23.0	−229.0(l)	−6124.5(l)
										—	−6171.0(g)
n-Octane	C_8H_{18}	114.22	0.703	−57.0	—	125.5	—	568.8	24.5	−249.9(l)	−5470.7(l)
										−208.4(g)	−5512.2(g)
Oxalic acid	$C_2H_2O_4$	90.04	1.90		Decomposes at 186°C			—	—	−826.8(c)	−251.9(s)
Oxygen	O_2	32.00	—	−218.75	0.444	−182.97	6.82	154.4	49.7	0(g)	—
n-Pentane	C_5H_{12}	72.15	$0.63^{18°}$	−129.6	8.393	36.07	25.77	469.80	33.3	−173.0(l)	−3509.5(l)
										−146.4(g)	−3536.1(g)
Isopentane	C_5H_{12}	72.15	$0.62^{19°}$	−160.1	—	27.7	—	461.00	32.9	−179.3(l)	−3507.5(l)
							—			−152.0(g)	−3529.2(g)
1-Pentene	C_5H_{10}	70.13	0.641	−165.2	4.94	29.97		474	39.9	−20.9(g)	−3375.8(g)
Phenol	C_6H_5OH	94.11	$1.071^{25°}$	42.5	11.43	181.4	—	692.1	60.5	−158.1(l)	−3063.5(s)
										−90.8(g)	—
Phosphoric acid	H_3PO_4	98.00	$1.834^{18°}$	42.3	10.54	$(-\frac{1}{2}H_2O$ at 213°C)		—	—	−1281.1(c)	—
										−1278.6(aq, $1H_2O$)	—
Phosphorus (red)	P_4	123.90	2.20	$590^{43\ atm}$	81.17	Ignites in air, 725°C		—	—	−17.6(c)	—
										0(c)	

Phosphorus (white)	P_4	123.90	1.82	44.2	2.51	280	49.71	—	—		—
Phosphorus pentoxide	P_2O_5	141.95	2.387	Sublimes at 250°C				—	—	−1506.2(c)	—
Propane	C_3H_8	44.09	—	−187.69	3.52	−42.07	18.77	369.9	42.0	−119.8(l) −103.8(g)	−2204.0(l) −2220.0(g)
Propylene	C_3H_6	42.08	—	−185.2	3.00	−47.70	18.42	365.1	45.4	+20.41(g)	−2058.4(g)
n-Propyl alcohol	C_3H_7OH	60.09	0.804	−127	—	97.04	—	536.7	49.95	−300.70(l) −255.2(g)	−2010.4(l) −2068.6(g)
Isopropyl alcohol	C_3H_7OH	60.09	0.785	−89.7	—	82.24	—	508.8	53.0	−310.9(l)	−1986.6(l)
n-Propyl benzene	C_9H_{12}	120.19	0.862	−99.50	8.54	159.2	38.24	638.7	31.3	−38.40(l) +7.82(g)	−5218.2(l) −5264.48(g)
Silicon dioxide	SiO_2	60.09	2.25	1710	14.2	2230	—	—	—	−851.0(c)	—
Sodium bicarbonate	$NaHCO_3$	84.01	2.20	Decomposes at 270°C				—	—	−945.6(c)	—
Sodium bisulfate	$NaHSO_4$	120.07	2.742	—	—	—	—	—	—	−1126.3(c)	—
Sodium carbonate	Na_2CO_3	105.99	2.533	Decomposes at 854°C				—	—	−1130.9(c)	—
Sodium chloride	NaCl	58.45	2.163	808	28.5	1465	170.7	—	—	−411.0(c)	—
Sodium cyanide	NaCN	49.01	—	562	16.7	1497	155	—	—	−89.79(c)	—
Sodium hydroxide	NaOH	40.00	2.130	319	8.34	1390	—	—	—	−426.6(c) −469.4(aq)	— —
Sodium nitrate	$NaNO_3$	85.00	2.257	310	15.9	Decomposes at 380°C			—	−466.7(c)	—
Sodium nitrite	$NaNO_2$	69.00	$2.168^{0°}$	271	—	Decomposes at 320°C			—	−359.4(c)	—
Sodium sulfate	Na_2SO_4	142.05	2.698	890	24.3	—	—	—	—	−1384.5(c)	—
Sodium sulfide	Na_2S	78.05	1.856	950	6.7	—	—	—	—	−373.2(c)	—
Sodium sulfite	Na_2SO_3	126.05	$2.633^{15°}$	Decomposes				—	—	−1090.3(c)	—

(*continued*)

Table B.1 (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f°)$[h,j] kJ/mol	$(\Delta\hat{H}_c°)$[i,j] kJ/mol
Sodium thiosulfate	$Na_2S_2O_3$	158.11	1.667	—	—	—	—	—	—	−1117.1(c)	—
Sulfur (rhombic)	S_8	256.53	2.07	113	10.04	444.6	83.7	—	—	0(c)	—
Sulfur (monoclinic)	S_8	256.53	1.96	119	14.17	444.6	83.7	—	—	+0.30(c)	—
Sulfur dioxide	SO_2	64.07	—	−75.48	7.402	−10.02	24.91	430.7	77.8	−296.90(g)	—
Sulfur trioxide	SO_3	80.07	—	16.84	25.48	43.3	41.80	491.4	83.8	−395.18(g)	—
Sulfuric acid	H_2SO_4	98.08	$1.834^{18°}$	10.35	9.87	Decomposes at 340°C		—	—	−811.32(l)	—
										−907.51(aq)	—
Toluene	C_7H_8	92.13	0.866	−94.99	6.619	110.62	33.47	593.9	40.3	+12.00(l)	−3909.9(l)
										+50.00(g)	−3947.9(g)
Water	H_2O	18.016	$1.00^{4°}$	0.00	6.0095	100.00	40.656	647.4	218.3	−285.84(l)	—
										−241.83(g)	—
m-Xylene	C_8H_{10}	106.16	0.864	−47.87	11.569	139.10	36.40	619	34.6	−25.42(l)	−4551.9(l)
										+17.24(g)	−4594.5(g)
o-Xylene	C_8H_{10}	106.16	0.880	−25.18	13.598	144.42	36.82	631.5	35.7	−24.44(l)	−4552.9(l)
										+18.99(g)	−4596.3(g)
p-Xylene	C_8H_{10}	106.16	0.861	13.26	17.11	138.35	36.07	618	33.9	−24.43(l)	−4552.91(l)
										17.95(g)	−4595.2(g)
Zinc	Zn	65.38	7.140	419.5	6.674	907	114.77	—	—	0(c)	—

Table B.2 Heat Capacities[a]

Physical Property database
Quickly integrates tabulated heat capacities

Form 1: C_p[kJ/(mol·°C)] or [kJ/(mol·K)] = $a + bT + cT^2 + dT^3$
Form 2: C_p[kJ/(mol·°C)] or [kJ/(mol·K)] = $a + bT + cT^{-2}$

Example: $(C_p)_{\text{acetone(g)}} = 0.07196 + (20.10 \times 10^{-5})T - (12.78 \times 10^{-8})T^2 + (34.76 \times 10^{-12})T^3$, where T is in °C.

Note: The formulas for gases are strictly applicable at pressures low enough for the ideal gas equation of state to apply.

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	$a \times 10^3$	$b \times 10^5$	$c \times 10^8$	$d \times 10^{12}$	Range (Units of T)
Acetone	CH_3COCH_3	58.08	l	1	°C	123.0	18.6			−30–60
			g	1	°C	71.96	20.10	−12.78	34.76	0–1200
Acetylene	C_2H_2	26.04	g	1	°C	42.43	6.053	−5.033	18.20	0–1200
Air		29.0	g	1	°C	28.94	0.4147	0.3191	−1.965	0–1500
			g	1	K	28.09	0.1965	0.4799	−1.965	273–1800
Ammonia	NH_3	17.03	g	1	°C	35.15	2.954	0.4421	−6.686	0–1200
Ammonium sulfate	$(NH_4)_2SO_4$	132.15	c	1	K	215.9				275–328
Benzene	C_6H_6	78.11	l	1	°C	126.5	23.4			6–67
			g	1	°C	74.06	32.95	−25.20	77.57	0–1200
Isobutane	C_4H_{10}	58.12	g	1	°C	89.46	30.13	−18.91	49.87	0–1200
n-Butane	C_4H_{10}	58.12	g	1	°C	92.30	27.88	−15.47	34.98	0–1200
Isobutene	C_4H_8	56.10	g	1	°C	82.88	25.64	−17.27	50.50	0–1200
Calcium carbide	CaC_2	64.10	c	2	K	68.62	1.19	-8.66×10^{10}	—	298–720
Calcium carbonate	$CaCO_3$	100.09	c	2	K	82.34	4.975	-12.87×10^{10}	—	273–1033
Calcium hydroxide	$Ca(OH)_2$	74.10	c	1	K	89.5				276–373
Calcium oxide	CaO	56.08	c	2	K	41.84	2.03	-4.52×10^{10}		273–1173
Carbon	C	12.01	c	2	K	11.18	1.095	-4.891×10^{10}		273–1373
Carbon dioxide	CO_2	44.01	g	1	°C	36.11	4.233	−2.887	7.464	0–1500
Carbon monoxide	CO	28.01	g	1	°C	28.95	0.4110	0.3548	−2.220	0–1500
Carbon tetrachloride	CCl_4	153.84	l	1	K	93.39	12.98			273–343
Chlorine	Cl_2	70.91	g	1	°C	33.60	1.367	−1.607	6.473	0–1200
Copper	Cu	63.54	c	1	K	22.76	0.6117			273–1357

[a]Adapted in part from D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering,* 3rd Edition, © 1974, Table E.1. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.

(*continued*)

Table B.2 (Continued)

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	$a \times 10^3$	$b \times 10^5$	$c \times 10^8$	$d \times 10^{12}$	Range (Units of T)
Cumene (Isopropyl benzene)	C_9H_{12}	120.19	g	1	°C	139.2	53.76	−39.79	120.5	0–1200
Cyclohexane	C_6H_{12}	84.16	g	1	°C	94.140	49.62	−31.90	80.63	0–1200
Cyclopentane	C_5H_{10}	70.13	g	1	°C	73.39	39.28	−25.54	68.66	0–1200
Ethane	C_2H_6	30.07	g	1	°C	49.37	13.92	−5.816	7.280	0–1200
Ethyl alcohol (Ethanol)	C_2H_5OH	46.07	l	1	°C	103.1				0
			l	1	°C	158.8				100
			g	1	°C	61.34	15.72	−8.749	19.83	0–1200
Ethylene	C_2H_4	28.05	g	1	°C	+40.75	11.47	−6.891	17.66	0–1200
Ferric oxide	Fe_2O_3	159.70	c	2	K	103.4	6.711	-17.72×10^{10}	—	273–1097
Formaldehyde	CH_2O	30.03	g	1	°C	34.28	4.268	0.0000	−8.694	0–1200
Helium	He	4.00	g	1	°C	20.8				0–1200
n-Hexane	C_6H_{14}	86.17	l	1	°C	216.3				20–100
			g	1	°C	137.44	40.85	−23.92	57.66	0–1200
Hydrogen	H_2	2.016	g	1	°C	28.84	0.00765	0.3288	−0.8698	0–1500
Hydrogen bromide	HBr	80.92	g	1	°C	29.10	−0.0227	0.9887	−4.858	0–1200
Hydrogen chloride	HCl	36.47	g	1	°C	29.13	−0.1341	0.9715	−4.335	0–1200
Hydrogen cyanide	HCN	27.03	g	1	°C	35.3	2.908	1.092		0–1200
Hydrogen sulfide	H_2S	34.08	g	1	°C	33.51	1.547	0.3012	−3.292	0–1500
Magnesium chloride	$MgCl_2$	95.23	c	1	K	72.4	1.58			273–991
Magnesium oxide	MgO	40.32	c	2	K	45.44	0.5008	-8.732×10^{10}		273–2073
Methane	CH_4	16.04	g	1	°C	34.31	5.469	0.3661	−11.00	0–1200
			g	1	K	19.87	5.021	1.268	−11.00	273–1500
Methyl alcohol (Methanol)	CH_3OH	32.04	l	1	°C	75.86	16.83			0–65
			g	1	°C	42.93	8.301	−1.87	−8.03	0–700
Methyl cyclohexane	C_7H_{14}	98.18	g	1	°C	121.3	56.53	−37.72	100.8	0–1200
Methyl cyclopentane	C_6H_{12}	84.16	g	1	°C	98.83	45.857	−30.44	83.81	0–1200
Nitric acid	NHO_3	63.02	l	1	°C	110.0				25
Nitric oxide	NO	30.01	g	1	°C	29.50	0.8188	−0.2925	0.3652	0–3500

Nitrogen	N_2	28.02	g	1	°C	29.00	0.2199	0.5723	−2.871	0–1500
Nitrogen dioxide	NO_2	46.01	g	1	°C	36.07	3.97	−2.88	7.87	0–1200
Nitrogen tetraoxide	N_2O_4	92.02	g	1	°C	75.7	12.5	−11.3		0–300
Nitrous oxide	N_2O	44.02	g	1	°C	37.66	4.151	−2.694	10.57	0–1200
Oxygen	O_2	32.00	g	1	°C	29.10	1.158	−0.6076	1.311	0–1500
n-Pentane	C_5H_{12}	72.15	l	1	°C	155.4	43.68			0–36
			g	1	°C	114.8	34.09	−18.99	42.26	0–1200
Propane	C_3H_8	44.09	g	1	°C	68.032	22.59	−13.11	31.71	0–1200
Propylene	C_3H_6	42.08	g	1	°C	59.580	17.71	−10.17	24.60	0–1200
Sodium carbonate	Na_2CO_3	105.99	c	1	K	121				288–371
Sodium carbonate decahydrate	$Na_2CO_3 \cdot 10H_2O$	286.15	c	1	K	535.6				298
Sulfur	S	32.07	c (Rhombic)	1	K	15.2	2.68			273–368
			c (Monoclinic)	1	K	18.3	1.84			368–392
Sulfuric acid	H_2SO_4	98.08	l	1	°C	139.1	15.59			10–45
Sulfur dioxide	SO_2	64.07	g	1	°C	38.91	3.904	−3.104	8.606	0–1500
Sulfur trioxide	SO_3	80.07	g	1	°C	48.50	9.188	−8.540	32.40	0–1000
Toluene	C_7H_8	92.13	l	1	°C	148.8	32.4			0–110
			g	1	°C	94.18	38.00	−27.86	80.33	0–1200
Water	H_2O	18.016	l	1	°C	75.4				0–100
			g	1	°C	33.46	0.6880	0.7604	−3.593	0–1500

Table B.3 Vapor Pressure of Water[a]

p_v(mm Hg) versus T(°C)

Example: The vapor pressure of liquid water at 4.3°C is 6.230 mm Hg

	T(°C)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
↓	−14	1.361	1.348	1.336	1.324	1.312	1.300	1.288	1.276	1.264	1.253
	−13	1.490	1.477	1.464	1.450	1.437	1.424	1.411	1.399	1.386	1.373
Ice	−12	1.632	1.617	1.602	1.588	1.574	1.559	1.546	1.532	1.518	1.504
	−11	1.785	1.769	1.753	1.737	1.722	1.707	1.691	1.676	1.661	1.646
	−10	1.950	1.934	1.916	1.899	1.883	1.866	1.849	1.833	1.817	1.800
	−9	2.131	2.122	2.093	2.075	2.057	2.039	2.021	2.003	1.985	1.968
	−8	2.326	2.306	2.285	2.266	2.246	2.226	2.207	2.187	2.168	2.149
	−7	2.537	2.515	2.493	2.472	2.450	2.429	2.408	2.387	2.367	2.346
	−6	2.765	2.742	2.718	2.695	2.672	2.649	2.626	2.603	2.581	2.559
	−5	3.013	2.987	2.962	2.937	2.912	2.887	2.862	2.838	2.813	2.790
	−4	3.280	3.252	3.225	3.198	3.171	3.144	3.117	3.091	3.065	3.039
	−3	3.568	3.539	3.509	3.480	3.451	3.422	3.393	3.364	3.336	3.308
	−2	3.880	3.848	3.816	3.785	3.753	3.722	3.691	3.660	3.630	3.599
	−1	4.217	4.182	4.147	4.113	4.079	4.045	4.012	3.979	3.946	3.913
	−0	4.579	4.542	4.504	4.467	4.431	4.395	4.359	4.323	4.287	4.252
↓	0	4.579	4.613	4.647	4.681	4.715	4.750	4.785	4.820	4.855	4.890
	1	4.926	4.962	4.998	5.034	5.070	5.107	5.144	5.181	5.219	5.256
Liquid	2	5.294	5.332	5.370	5.408	5.447	5.486	5.525	5.565	5.605	5.645
water	3	5.685	5.725	5.766	5.807	5.848	5.889	5.931	5.973	6.015	6.058
	4	6.101	6.144	6.187	6.230	6.274	6.318	6.363	6.408	6.453	6.498
	5	6.543	6.589	6.635	6.681	6.728	6.775	6.822	6.869	6.917	6.965
	6	7.013	7.062	7.111	7.160	7.209	7.259	7.309	7.360	7.411	7.462
	7	7.513	7.565	7.617	7.669	7.722	7.775	7.828	7.882	7.936	7.990
	8	8.045	8.100	8.155	8.211	8.267	8.323	8.380	8.437	8.494	8.551
	9	8.609	8.668	8.727	8.786	8.845	8.905	8.965	9.025	9.086	9.147
	10	9.209	9.271	9.333	9.395	9.458	9.521	9.585	9.649	9.714	9.779
	11	9.844	9.910	9.976	10.042	10.109	10.176	10.244	10.312	10.380	10.449
	12	10.518	10.588	10.658	10.728	10.799	10.870	10.941	11.013	11.085	11.158
	13	11.231	11.305	11.379	11.453	11.528	11.604	11.680	11.756	11.833	11.910
	14	11.987	12.065	12.144	12.223	12.302	12.382	12.462	12.543	12.624	12.706
	15	12.788	12.870	12.953	13.037	13.121	13.205	13.290	13.375	13.461	13.547
	16	13.634	13.721	13.809	13.898	13.987	14.076	14.166	14.256	14.347	14.438
	17	14.530	14.622	14.715	14.809	14.903	14.997	15.092	15.188	15.284	15.380
	18	15.477	15.575	15.673	15.772	15.871	15.971	16.771	16.171	16.272	16.374
	19	16.477	16.581	16.685	16.789	16.894	16.999	17.105	17.212	17.319	17.427
	20	17.535	17.644	17.753	17.863	17.974	18.085	18.197	18.309	18.422	18.536
	21	18.650	18.765	18.880	18.996	19.113	19.231	19.349	19.468	19.587	19.707
	22	19.827	19.948	20.070	20.193	20.316	20.440	20.565	20.690	20.815	20.941
	23	21.068	21.196	21.324	21.453	21.583	21.714	21.845	21.977	22.110	22.243
	24	22.377	22.512	22.648	22.785	22.922	23.060	23.198	23.337	23.476	23.616

[a]From R. H. Perry and C. H. Chilton, Eds., *Chemical Engineers' Handbook*, 5th Edition, McGraw-Hill, New York, 1973, Tables 3-3 and 3-5. Reprinted by permission of McGraw-Hill Book Co.

(*continued*)

Table B.3 (Continued)

T(°C)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
25	23.756	23.897	24.039	24.182	24.326	24.471	24.617	24.764	24.912	25.060
26	25.209	25.359	25.509	25.660	25.812	25.964	26.117	26.271	26.426	26.582
27	26.739	26.897	27.055	27.214	27.374	27.535	27.696	27.858	28.021	28.185
28	28.349	28.514	28.680	28.847	29.015	29.184	29.354	29.525	29.697	29.870
29	30.043	30.217	30.392	30.568	30.745	30.923	31.102	31.281	31.461	31.642
30	31.824	32.007	32.191	32.376	32.561	32.747	32.934	33.122	33.312	33.503
31	33.695	33.888	34.082	34.276	34.471	34.667	34.864	35.062	35.261	35.462
32	35.663	35.865	36.068	36.272	36.477	36.683	36.891	37.099	37.308	37.518
33	37.729	37.942	38.155	38.369	33.584	38.801	38.018	39.237	39.457	39.677
34	39.898	40.121	40.344	40.569	40.796	41.023	41.251	41.480	41.710	41.942
35	42.175	42.409	42.644	42.880	43.117	43.355	43.595	43.836	44.078	44.320
36	44.563	44.808	45.054	45.301	45.549	45.799	46.050	46.302	46.556	46.811
37	47.067	47.324	47.582	47.841	48.102	48.364	48.627	48.891	49.157	49.424
38	49.692	49.961	50.231	50.502	50.774	51.048	51.323	51.600	51.879	52.160
39	52.442	52.725	53.009	53.294	53.580	53.867	54.156	54.446	54.737	55.030
40	55.324	55.61	55.91	56.21	56.51	56.81	57.11	57.41	57.72	58.03
41	58.34	58.65	58.96	59.27	59.58	59.90	60.22	60.54	60.86	61.18
42	61.50	61.82	62.14	62.47	62.80	63.13	63.46	63.79	64.12	64.46
43	64.80	65.14	65.48	65.82	66.16	66.51	66.86	67.21	67.56	67.91
44	68.26	68.61	68.97	69.33	69.69	70.05	70.41	70.77	71.14	71.51
45	71.88	72.25	72.62	72.99	73.36	73.74	74.12	74.50	74.88	75.26
46	75.65	76.04	76.43	76.82	77.21	77.60	78.00	78.40	78.80	79.20
47	79.60	80.00	80.41	80.82	81.23	81.64	82.05	82.46	82.87	83.29
48	83.71	84.13	84.56	84.99	85.42	85.85	86.28	86.71	87.14	87.58
49	88.02	88.46	88.90	89.34	89.79	90.24	90.69	91.14	91.59	92.05

T(°C)	0	1	2	3	4	5	6	7	8	9
50	92.51	97.20	102.09	107.20	112.51	118.04	123.80	129.82	136.08	142.60
60	149.38	156.43	163.77	171.38	179.31	187.54	196.09	204.96	214.17	223.73
70	233.7	243.9	254.6	265.7	277.2	289.1	301.4	314.1	327.3	341.0
80	355.1	369.7	384.9	400.6	416.8	433.6	450.9	468.7	487.1	506.1

T(°C)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
90	525.76	527.76	529.77	531.78	533.80	535.82	537.86	539.90	541.95	544.00
91	546.05	548.11	550.18	552.26	554.35	556.44	558.53	560.64	562.75	564.87
92	566.99	569.12	571.26	573.40	575.55	577.71	579.87	582.04	584.22	586.41
93	588.60	590.80	593.00	595.21	597.43	599.66	601.89	604.13	606.38	608.64
94	610.90	613.17	615.44	617.72	620.01	622.31	624.61	626.92	629.24	631.57
95	633.90	636.24	938.59	640.94	643.30	645.67	648.05	650.43	652.82	655.22
96	657.62	660.03	662.45	664.88	667.31	669.75	672.20	674.66	677.12	679.69
97	682.07	684.55	687.04	689.54	692.05	694.57	697.10	699.63	702.17	704.71
98	707.27	709.83	712.40	714.98	717.56	720.15	722.75	725.36	727.98	730.61
99	733.24	735.88	738.53	741.18	743.85	746.52	749.20	751.89	754.58	757.29
100	760.00	762.72	765.45	768.19	770.93	773.68	776.44	779.22	782.00	784.78
101	787.57	790.37	793.18	796.00	798.82	801.66	804.50	807.35	810.21	813.08

Table B.4 Antoine Equation Constants[a]

$$\log_{10} p^* = A - \frac{B}{T + C} \qquad p^* \text{ in mm Hg}, \quad T \text{ in °C}$$

Example: The vapor pressure of acetaldehyde at 25°C is determined as follows:

$$\log_{10} p^*_{C_2H_4O}(25°C) = 8.00552 - \frac{1600.017}{25 + 291.809} = 2.9551$$

$$\Longrightarrow p^*_{C_2H_4O}(25°C) = 10^{2.9551} = 902 \text{ mm Hg}$$

Compound	Formula	Range (°C)	*A*	*B*	*C*
Acetaldehyde	C_2H_4O	−0.2 to 34.4	8.00552	1600.017	291.809
Acetic acid	$C_2H_4O_2$	29.8 to 126.5	7.38782	1533.313	222.309
Acetic acid*	$C_2H_4O_2$	0 to 36	7.18807	1416.7	225
Acetic anhydride	$C_4H_6O_3$	62.8 to 139.4	7.14948	1444.718	199.817
Acetone	C_3H_6O	−12.9 to 55.3	7.11714	1210.595	229.664
Acrylic acid	$C_3H_4O_2$	20.0 to 70.0	5.65204	648.629	154.683
Ammonia*	NH_3	−83 to 60	7.55466	1002.711	247.885
Aniline	C_6H_7N	102.6 to 185.2	7.32010	1731.515	206.049
Benzene	C_6H_6	14.5 to 80.9	6.89272	1203.531	219.888
n-Butane	n-C_4H_{10}	−78.0 to −0.3	6.82485	943.453	239.711
i-Butane	i-C_4H_{10}	−85.1 to −11.6	6.78866	899.617	241.942
1-Butanol	$C_4H_{10}O$	89.2 to 125.7	7.36366	1305.198	173.427
2-Butanol	$C_4H_{10}O$	72.4 to 107.1	7.20131	1157.000	168.279
1-Butene	C_4H_8	−77.5 to −3.7	6.53101	810.261	228.066
Butyric acid	$C_4H_8O_2$	20.0 to 150.0	8.71019	2433.014	255.189
Carbon disulfide	CS_2	3.6 to 79.9	6.94279	1169.110	241.593
Carbon tetrachloride	CCl_4	14.1 to 76.0	6.87926	1212.021	226.409
Chlorobenzene	C_6H_5Cl	62.0 to 131.7	6.97808	1431.053	217.550
Chlorobenzene*	C_6H_5Cl	0 to 42	7.10690	1500.0	224.0
Chlorobenzene*	C_6H_5Cl	42 to 230	6.94504	1413.12	216.0
Chloroform	$CHCl_3$	−10.4 to 60.3	6.95465	1170.966	226.232
Chloroform*	$CHCl_3$	−30 to 150	6.90328	1163.03	227.4
Cyclohexane	C_6H_{12}	19.9 to 81.6	6.84941	1206.001	223.148
Cyclohexanol	$C_6H_{12}O$	93.7 to 160.7	6.25530	912.866	109.126
n-Decane	n-$C_{10}H_{22}$	94.5 to 175.1	6.95707	1503.568	194.738
1-Decene	$C_{10}H_{20}$	86.8 to 171.6	6.95433	1497.527	197.056
1,1-Dichloroethane	$C_2H_4Cl_2$	−38.8 to 17.6	6.97702	1174.022	229.060
1,2-Dichloroethane	C_2H_4Cl	−30.8 to 99.4	7.02530	1271.254	222.927
Dichloromethane	CH_2Cl_2	−40.0 to 40	7.40916	1325.938	252.616
Diethyl ether	$C_4H_{10}O$	−60.8 to 19.9	6.92032	1064.066	228.799
Diethyl ketone	$C_5H_{10}O$	56.5 to 111.3	7.02529	1310.281	214.192
Diethylene glycol	$C_4H_{10}O_2$	130.0 to 243.0	7.63666	1939.359	162.714
Dimethyl ether	C_2H_6O	−78.2 to −24.9	6.97603	889.264	241.957
Dimethylamine	C_2H_7N	−71.8 to 6.9	7.08212	960.242	221.667
N,*N*-Dimethylformamide	C_3H_7NO	30.0 to 90.0	6.92796	1400.869	196.434
1,4-Dioxane	$C_4H_8O_2$	20.0 to 105.0	7.43155	1554.679	240.337
Ethanol	C_2H_6O	19.6 to 93.4	8.11220	1592.864	226.184
Ethanolamine	C_2H_7NO	65.4 to 170.9	7.45680	1577.670	173.368
Ethyl acetate	$C_4H_8O_2$	15.6 to 75.8	7.10179	1244.951	217.881
Ethyl acetate*	$C_4H_8O_2$	−20 to 150	7.09808	1238.710	217.0
Ethyl chloride	C_2H_5Cl	−55.9 to 12.5	6.98647	1030.007	238.612
Ethylbenzene	C_8H_{10}	56.5 to 137.1	6.95650	1423.543	213.091

[a]Adapted from T. Boublik, V. Fried, and E. Hala, *The Vapour Pressures of Pure Substances*, Elsevier, Amsterdam, 1973. If marked with an asterisk (*), constants are from *Lange's Handbook of Chemistry*, 9th Edition, Handbook Publishers, Inc., Sandusky, OH, 1956.

(*continued*)

Table B.4 (Continued)

Compound	Formula	Range (°C)	*A*	*B*	*C*
Ethylene glycol	$C_2H_6O_2$	50.0 to 200.0	8.09083	2088.936	203.454
Ethylene oxide	C_2H_4O	0.3 to 31.8	8.69016	2005.779	334.765
1,2-Ethylenediamine	$C_2H_8N_2$	26.5 to 117.4	7.16871	1336.235	194.366
Formaldehyde	HCHO	−109.4 to −22.3	7.19578	970.595	244.124
Formic acid	CH_2O_2	37.4 to 100.7	7.58178	1699.173	260.714
Glycerol	$C_3H_8O_3$	183.3 to 260.4	6.16501	1036.056	28.097
n-Heptane	*n*-C_7H_{16}	25.9 to 99.3	6.90253	1267.828	216.823
i-Heptane	*i*-C_7H_{16}	18.5 to 90.9	6.87689	1238.122	219.783
1-Heptene	C_7H_{14}	21.6 to 94.5	6.91381	1265.120	220.051
n-Hexane	*n*-C_6H_{14}	13.0 to 69.5	6.88555	1175.817	224.867
i-Hexane	*i*-C_6H_{14}	12.8 to 61.1	6.86839	1151.401	228.477
1-Hexene	C_6H_{12}	15.9 to 64.3	6.86880	1154.646	226.046
Hydrogen Cyanide	HCN	−16.4 to 46.2	7.52823	1329.49	260.418
Methanol	CH_3OH	14.9 to 83.7	8.08097	1582.271	239.726
Methanol*	CH_3OH	−20 to 140	7.87863	1473.11	230.0
Methyl acetate	$C_3H_6O_2$	1.8 to 55.8	7.06524	1157.630	219.726
Methyl bromide	CH_3Br	−70.0 to 3.6	7.09084	1046.066	244.914
Methyl chloride	CH_3Cl	−75.0 to 5.0	7.09349	948.582	249.336
Methyl ethyl ketone	C_4H_8O	42.8 to 88.4	7.06356	1261.339	221.969
Methyl isobutyl ketone	$C_6H_{12}O$	21.7 to 116.2	6.67272	1168.408	191.944
Methyl methacrylate	$C_5H_8O_2$	39.2 to 89.2	8.40919	2050.467	274.369
Methylamine	CH_5N	−83.1 to −6.2	7.33690	1011.532	233.286
Methylcyclohexane	C_7H_{14}	25.6 to 101.8	6.82827	1273.673	221.723
Naphthalene	$C_{10}H_8$	80.3 to 179.5	7.03358	1756.328	204.842
Nitrobenzene	$C_6H_5NO_2$	134.1 to 210.6	7.11562	1746.586	201.783
Nitromethane	CH_3NO_2	55.7 to 136.4	7.28166	1446.937	227.600
n-Nonane	*n*-C_9H_{20}	70.3 to 151.8	6.93764	1430.459	201.808
1-Nonene	C_9H_{18}	66.6 to 147.9	6.95777	1437.862	205.814
n-Octane	*n*-C_8H_{18}	52.9 to 126.6	6.91874	1351.756	209.100
i-Octane	*i*-C_8H_{18}	41.7 to 118.5	6.88814	1319.529	211.625
1-Octene	C_8H_{16}	44.9 to 122.2	6.93637	1355.779	213.022
n-Pentane	*n*-C_5H_{12}	13.3 to 36.8	6.84471	1060.793	231.541
i-Pentane	*i*-C_5H_{12}	16.3 to 28.6	6.73457	992.019	229.564
1-Pentanol	$C_5H_{12}O$	74.7 to 156.0	7.18246	1287.625	161.330
1-Pentene	C_5H_{10}	12.8 to 30.7	6.84268	1043.206	233.344
Phenol	C_6H_6O	107.2 to 181.8	7.13301	1516.790	174.954
1-Propanol	C_3H_8O	60.2 to 104.6	7.74416	1437.686	198.463
2-Propanol	C_3H_8O	52.3 to 89.3	7.74021	1359.517	197.527
Propionic acid	$C_3H_6O_2$	72.4 to 128.3	7.71423	1733.418	217.724
Propylene oxide	C_3H_6O	−24.2 to 34.8	7.01443	1086.369	228.594
Pyridine	C_5H_5N	67.3 to 152.9	7.04115	1373.799	214.979
Styrene	C_8H_8	29.9 to 144.8	7.06623	1507.434	214.985
Toluene	C_7H_8	35.3 to 111.5	6.95805	1346.773	219.693
1,1,1-Trichloroethane	$C_2H_3Cl_3$	−5.4 to 16.9	8.64344	2136.621	302.769
1,1,2-Trichloroethane	$C_2H_3Cl_3$	50.0 to 113.7	6.95185	1314.410	209.197
Trichloroethylene	C_2HCl_3	17.8 to 86.5	6.51827	1018.603	192.731
Vinyl acetate	$C_4H_6O_2$	21.8 to 72.0	7.21010	1296.130	226.655
Water*	H_2O	0 to 60	8.10765	1750.286	235.000
Water*	H_2O	60 to 150	7.96681	1668.210	228.000
m-Xylene	*m*-C_8H_{10}	59.2 to 140.0	7.00646	1460.183	214.827
o-Xylene	*o*-C_8H_{10}	63.5 to 145.4	7.00154	1476.393	213.872
p-Xylene	*p*-C_8H_{10}	58.3 to 139.3	6.98820	1451.792	215.111

Table B.5 Properties of Saturated Steam: Temperature Table[a]

		$\hat{V}$(m³/kg)		$\hat{U}$(kJ/kg)		$\hat{H}$(kJ/kg)		
T(°C)	P(bar)	Water	Steam	Water	Steam	Water	Evaporation	Steam
0.01	0.00611	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
2	0.00705	0.001000	179.9	8.4	2378.3	8.4	2496.8	2505.2
4	0.00813	0.001000	157.3	16.8	2381.1	16.8	2492.1	2508.9
6	0.00935	0.001000	137.8	25.2	2383.8	25.2	2487.4	2512.6
8	0.01072	0.001000	121.0	33.6	2386.6	33.6	2482.6	2516.2
10	0.01227	0.001000	106.4	42.0	2389.3	42.0	2477.9	2519.9
12	0.01401	0.001000	93.8	50.4	2392.1	50.4	2473.2	2523.6
14	0.01597	0.001001	82.9	58.8	2394.8	58.8	2468.5	2527.2
16	0.01817	0.001001	73.4	67.1	2397.6	67.1	2463.8	2530.9
18	0.02062	0.001001	65.1	75.5	2400.3	75.5	2459.0	2534.5
20	0.0234	0.001002	57.8	83.9	2403.0	83.9	2454.3	2538.2
22	0.0264	0.001002	51.5	92.2	2405.8	92.2	2449.6	2541.8
24	0.0298	0.001003	45.9	100.6	2408.5	100.6	2444.9	2545.5
25	0.0317	0.001003	43.4	104.8	2409.9	104.8	2442.5	2547.3
26	0.0336	0.001003	41.0	108.9	2411.2	108.9	2440.2	2549.1
28	0.0378	0.001004	36.7	117.3	2414.0	117.3	2435.4	2552.7
30	0.0424	0.001004	32.9	125.7	2416.7	125.7	2430.7	2556.4
32	0.0475	0.001005	29.6	134.0	2419.4	134.0	2425.9	2560.0
34	0.0532	0.001006	26.6	142.4	2422.1	142.4	2421.2	2563.6
36	0.0594	0.001006	24.0	150.7	2424.8	150.7	2416.4	2567.2
38	0.0662	0.001007	21.6	159.1	2427.5	159.1	2411.7	2570.8
40	0.0738	0.001008	19.55	167.4	2430.2	167.5	2406.9	2574.4
42	0.0820	0.001009	17.69	175.8	2432.9	175.8	2402.1	2577.9
44	0.0910	0.001009	16.04	184.2	2435.6	184.2	2397.3	2581.5
46	0.1009	0.001010	14.56	192.5	2438.3	192.5	2392.5	2585.1
48	0.1116	0.001011	13.23	200.9	2440.9	200.9	2387.7	2588.6
50	0.1234	0.001012	12.05	209.2	2443.6	209.3	2382.9	2592.2
52	0.1361	0.001013	10.98	217.7	2446	217.7	2377	2595
54	0.1500	0.001014	10.02	226.0	2449	226.0	2373	2599
56	0.1651	0.001015	9.158	234.4	2451	234.4	2368	2602
58	0.1815	0.001016	8.380	242.8	2454	242.8	2363	2606
60	0.1992	0.001017	7.678	251.1	2456	251.1	2358	2609
62	0.2184	0.001018	7.043	259.5	2459	259.5	2353	2613
64	0.2391	0.001019	6.468	267.9	2461	267.9	2348	2616
66	0.2615	0.001020	5.947	276.2	2464	276.2	2343	2619
68	0.2856	0.001022	5.475	284.6	2467	284.6	2338	2623

[a]From R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units,* Cambridge University Press, London, 1968. $\hat{V}$ = specific volume, $\hat{U}$ = specific internal energy, and $\hat{H}$ = specific enthalpy. *Note:* kJ/kg × 0.4303 = Btu/lb$_m$.

(*continued*)

Table B.5 (Continued)

		$\hat{V}$(m³/kg)		$\hat{U}$(kJ/kg)		$\hat{H}$(kJ/kg)		
T(°C)	P(bar)	Water	Steam	Water	Steam	Water	Evaporation	Steam
70	0.3117	0.001023	5.045	293.0	2469	293.0	2333	2626
72	0.3396	0.001024	4.655	301.4	2472	301.4	2329	2630
74	0.3696	0.001025	4.299	309.8	2474	309.8	2323	2633
76	0.4019	0.001026	3.975	318.2	2476	318.2	2318	2636
78	0.4365	0.001028	3.679	326.4	2479	326.4	2313	2639
80	0.4736	0.001029	3.408	334.8	2482	334.9	2308	2643
82	0.5133	0.001030	3.161	343.2	2484	343.3	2303	2646
84	0.5558	0.001032	2.934	351.6	2487	351.7	2298	2650
86	0.6011	0.001033	2.727	360.0	2489	360.1	2293	2653
88	0.6495	0.001034	2.536	368.4	2491	368.5	2288	2656
90	0.7011	0.001036	2.361	376.9	2493	377.0	2282	2659
92	0.7560	0.001037	2.200	385.3	2496	385.4	2277	2662
94	0.8145	0.001039	2.052	393.7	2499	393.8	2272	2666
96	0.8767	0.001040	1.915	402.1	2501	402.2	2267	2669
98	0.9429	0.001042	1.789	410.6	2504	410.7	2262	2673
100	1.0131	0.001044	1.673	419.0	2507	419.1	2257	2676
102	1.0876	0.001045	1.566	427.1	2509	427.5	2251	2679

Table B.6 Properties of Saturated Steam: Pressure Table[a]

		$\hat{V}$(m³/kg)		$\hat{U}$(kJ/kg)		$\hat{H}$(kJ/kg)		
P(bar)	T(°C)	Water	Steam	Water	Steam	Water	Evaporation	Steam
0.00611	0.01	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
0.008	3.8	0.001000	159.7	15.8	2380.7	15.8	2492.6	2508.5
0.010	7.0	0.001000	129.2	29.3	2385.2	29.3	2485.0	2514.4
0.012	9.7	0.001000	108.7	40.6	2388.9	40.6	2478.7	2519.3
0.014	12.0	0.001000	93.9	50.3	2392.0	50.3	2473.2	2523.5
0.016	14.0	0.001001	82.8	58.9	2394.8	58.9	2468.4	2527.3
0.018	15.9	0.001001	74.0	66.5	2397.4	66.5	2464.1	2530.6
0.020	17.5	0.001001	67.0	73.5	2399.6	73.5	2460.2	2533.6
0.022	19.0	0.001002	61.2	79.8	2401.7	79.8	2456.6	2536.4
0.024	20.4	0.001002	56.4	85.7	2403.6	85.7	2453.3	2539.0
0.026	21.7	0.001002	52.3	91.1	2405.4	91.1	2450.2	2541.3
0.028	23.0	0.001002	48.7	96.2	2407.1	96.2	2447.3	2543.6
0.030	24.1	0.001003	45.7	101.0	2408.6	101.0	2444.6	2545.6
0.035	26.7	0.001003	39.5	111.8	2412.2	111.8	2438.5	2550.4
0.040	29.0	0.001004	34.8	121.4	2415.3	121.4	2433.1	2554.5
0.045	31.0	0.001005	31.1	130.0	2418.1	130.0	2428.2	2558.2
0.050	32.9	0.001005	28.2	137.8	2420.6	137.8	2423.8	2561.6
0.060	36.2	0.001006	23.74	151.5	2425.1	151.5	2416.0	2567.5
0.070	39.0	0.001007	20.53	163.4	2428.9	163.4	2409.2	2572.6
0.080	41.5	0.001008	18.10	173.9	2432.3	173.9	2403.2	2577.1
0.090	43.8	0.001009	16.20	183.3	2435.3	183.3	2397.9	2581.1
0.10	45.8	0.001010	14.67	191.8	2438.0	191.8	2392.9	2584.8
0.11	47.7	0.001011	13.42	199.7	2440.5	199.7	2388.4	2588.1
0.12	49.4	0.001012	12.36	206.9	2442.8	206.9	2384.3	2591.2
0.13	51.1	0.001013	11.47	213.7	2445.0	213.7	2380.4	2594.0
0.14	52.6	0.001013	10.69	220.0	2447.0	220.0	2376.7	2596.7

0.15	54.0	0.001014	10.02	226.0	2448.9	226.0	2373.2	2599.2
0.16	55.3	0.001015	9.43	231.6	2450.6	231.6	2370.0	2601.6
0.17	56.6	0.001015	8.91	236.9	2452.3	236.9	2366.9	2603.8
0.18	57.8	0.001016	8.45	242.0	2453.9	242.0	2363.9	2605.9
0.19	59.0	0.001017	8.03	246.8	2455.4	246.8	2361.1	2607.9
0.20	60.1	0.001017	7.65	251.5	2456.9	251.5	2358.4	2609.9
0.22	62.2	0.001018	7.00	260.1	2459.6	260.1	2353.3	2613.5
0.24	64.1	0.001019	6.45	268.2	2462.1	268.2	2348.6	2616.8
0.26	65.9	0.001020	5.98	275.6	2464.4	275.7	2344.2	2619.9
0.28	67.5	0.001021	5.58	282.7	2466.5	282.7	2340.0	2622.7
0.30	69.1	0.001022	5.23	289.3	2468.6	289.3	2336.1	2625.4
0.35	72.7	0.001025	4.53	304.3	2473.1	304.3	2327.2	2631.5
0.40	75.9	0.001027	3.99	317.6	2477.1	317.7	2319.2	2636.9
0.45	78.7	0.001028	3.58	329.6	2480.7	329.6	2312.0	2641.7
0.50	81.3	0.001030	3.24	340.5	2484.0	340.6	2305.4	2646.0
0.55	83.7	0.001032	2.96	350.6	2486.9	350.6	2299.3	2649.9
0.60	86.0	0.001033	2.73	359.9	2489.7	359.9	2293.6	2653.6
0.65	88.0	0.001035	2.53	368.5	2492.2	368.6	2288.3	2656.9
0.70	90.0	0.001036	2.36	376.7	2494.5	376.8	2283.3	2660.1
0.75	91.8	0.001037	2.22	384.4	2496.7	384.5	2278.6	2663.0
0.80	93.5	0.001039	2.087	391.6	2498.8	391.7	2274.1	2665.8
0.85	95.2	0.001040	1.972	398.5	2500.8	398.6	2269.8	2668.4
0.90	96.7	0.001041	1.869	405.1	2502.6	405.2	2265.6	2670.9
0.95	98.2	0.001042	1.777	411.4	2504.4	411.5	2261.7	2673.2
1.00	99.6	0.001043	1.694	417.4	2506.1	417.5	2257.9	2675.4
1.01325 (1 atm)	100.0	0.001044	1.673	419.0	2506.5	419.1	2256.9	2676.0

[a]From R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units,* Cambridge University Press, London, 1968. $\hat{V}$ = specific volume, $\hat{U}$ = specific internal energy, and $\hat{H}$ = specific enthalpy. *Note:* kJ/kg × 0.4303 = Btu/lb_m.

(*continued*)

Table B.6 (Continued)

		$\hat{V}$(m³/kg)		$\hat{U}$(kJ/kg)		$\hat{H}$(kJ/kg)		
P(bar)	T(°C)	Water	Steam	Water	Steam	Water	Evaporation	Steam
1.1	102.3	0.001046	1.549	428.7	2509.2	428.8	2250.8	2679.6
1.2	104.8	0.001048	1.428	439.2	2512.1	439.4	2244.1	2683.4
1.3	107.1	0.001049	1.325	449.1	2514.7	449.2	2237.8	2687.0
1.4	109.3	0.001051	1.236	458.3	2517.2	458.4	2231.9	2690.3
1.5	111.4	0.001053	1.159	467.0	2519.5	467.1	2226.2	2693.4
1.6	113.3	0.001055	1.091	475.2	2521.7	475.4	2220.9	2696.2
1.7	115.2	0.001056	1.031	483.0	2523.7	483.2	2215.7	2699.0
1.8	116.9	0.001058	0.977	490.5	2525.6	490.7	2210.8	2701.5
1.9	118.6	0.001059	0.929	497.6	2527.5	497.8	2206.1	2704.0
2.0	120.2	0.001061	0.885	504.5	2529.2	504.7	2201.6	2706.3
2.2	123.3	0.001064	0.810	517.4	2532.4	517.6	2193.0	2710.6
2.4	126.1	0.001066	0.746	529.4	2535.4	529.6	2184.9	2714.5
2.6	128.7	0.001069	0.693	540.6	2538.1	540.9	2177.3	2718.2
2.8	131.2	0.001071	0.646	551.1	2540.6	551.4	2170.1	2721.5
3.0	133.5	0.001074	0.606	561.1	2543.0	561.4	2163.2	2724.7
3.2	135.8	0.001076	0.570	570.6	2545.2	570.9	2156.7	2727.6
3.4	137.9	0.001078	0.538	579.6	2547.2	579.9	2150.4	2730.3
3.6	139.9	0.001080	0.510	588.1	2549.2	588.5	2144.4	2732.9
3.8	141.8	0.001082	0.485	596.4	2551.0	596.8	2138.6	2735.3
4.0	143.6	0.001084	0.462	604.2	2552.7	604.7	2133.0	2737.6
4.2	145.4	0.001086	0.442	611.8	2554.4	612.3	2127.5	2739.8
4.4	147.1	0.001088	0.423	619.1	2555.9	619.6	2122.3	2741.9
4.6	148.7	0.001089	0.405	626.2	2557.4	626.7	2117.2	2743.9
4.8	150.3	0.001091	0.389	633.0	2558.8	633.5	2112.2	2745.7
5.0	151.8	0.001093	0.375	639.6	2560.2	640.1	2107.4	2747.5
5.5	155.5	0.001097	0.342	655.2	2563.3	655.8	2095.9	2751.7
6.0	158.8	0.001101	0.315	669.8	2566.2	670.4	2085.0	2755.5
6.5	162.0	0.001105	0.292	683.4	2568.7	684.1	2074.7	2758.9
7.0	165.0	0.001108	0.273	696.3	2571.1	697.1	2064.9	2762.0

7.5	167.8	0.001112	0.2554	708.5	2573.3	709.3	2055.5	2764.8
8.0	170.4	0.001115	0.2403	720.0	2575.5	720.9	2046.5	2767.5
8.5	172.9	0.001118	0.2268	731.1	2577.1	732.0	2037.9	2769.9
9.0	175.4	0.001121	0.2148	741.6	2578.8	742.6	2029.5	2772.1
9.5	177.7	0.001124	0.2040	751.8	2580.4	752.8	2021.4	2774.2
10.0	179.9	0.001127	0.1943	761.5	2581.9	762.6	2013.6	2776.2
10.5	182.0	0.001130	0.1855	770.8	2583.3	772.0	2005.9	2778.0
11.0	184.1	0.001133	0.1774	779.9	2584.5	781.1	1998.5	2779.7
11.5	186.0	0.001136	0.1700	788.6	2585.8	789.9	1991.3	2781.3
12.0	188.0	0.001139	0.1632	797.1	2586.9	798.4	1984.3	2782.7
12.5	189.8	0.001141	0.1569	805.3	2588.0	806.7	1977.4	2784.1
13.0	191.6	0.001144	0.1511	813.2	2589.0	814.7	1970.7	2785.4
14	195.0	0.001149	0.1407	828.5	2590.8	830.1	1957.7	2787.8
15	198.3	0.001154	0.1317	842.9	2592.4	844.7	1945.2	2789.9
16	201.4	0.001159	0.1237	856.7	2593.8	858.6	1933.2	2791.7
17	204.3	0.001163	0.1166	869.9	2595.1	871.8	1921.5	2793.4
18	207.1	0.001168	0.1103	882.5	2596.3	884.6	1910.3	2794.8
19	209.8	0.001172	0.1047	894.6	2597.3	896.8	1899.3	2796.1
20	212.4	0.001177	0.0995	906.2	2598.2	908.6	1888.6	2797.2
21	214.9	0.001181	0.0949	917.5	2598.9	920.0	1878.2	2798.2
22	217.2	0.001185	0.0907	928.3	2599.6	931.0	1868.1	2799.1
23	219.6	0.001189	0.0868	938.9	2600.2	941.6	1858.2	2799.8
24	221.8	0.001193	0.0832	949.1	2600.7	951.9	1848.5	2800.4
25	223.9	0.001197	0.0799	959.0	2601.2	962.0	1839.0	2800.9
26	226.0	0.001201	0.0769	968.6	2601.5	971.7	1829.6	2801.4
27	228.1	0.001205	0.0740	978.0	2601.8	981.2	1820.5	2801.7
28	230.0	0.001209	0.0714	987.1	2602.1	990.5	1811.5	2802.0
29	232.0	0.001213	0.0689	996.0	2602.3	999.5	1802.6	2802.2
30	233.8	0.001216	0.0666	1004.7	2602.4	1008.4	1793.9	2802.3
32	237.4	0.001224	0.0624	1021.5	2602.5	1025.4	1776.9	2802.3
34	240.9	0.001231	0.0587	1037.6	2602.5	1041.8	1760.3	2802.1
36	244.2	0.001238	0.0554	1053.1	2602.2	1057.6	1744.2	2801.7
38	247.3	0.001245	0.0524	1068.0	2601.9	1072.7	1728.4	2801.1

(*continued*)

Table B.6 (Continued)

		$\hat{V}$(m³/kg)		$\hat{U}$(kJ/kg)		$\hat{H}$(kJ/kg)		
P(bar)	T(°C)	Water	Steam	Water	Steam	Water	Evaporation	Steam
40	250.3	0.001252	0.0497	1082.4	2601.3	1087.4	1712.9	2800.3
42	253.2	0.001259	0.0473	1096.3	2600.7	1101.6	1697.8	2799.4
44	256.0	0.001266	0.0451	1109.8	2599.9	1115.4	1682.9	2798.3
46	258.8	0.001272	0.0430	1122.9	2599.1	1128.8	1668.3	2797.1
48	261.4	0.001279	0.0412	1135.6	2598.1	1141.8	1653.9	2795.7
50	263.9	0.001286	0.0394	1148.0	2597.0	1154.5	1639.7	2794.2
52	266.4	0.001292	0.0378	1160.1	2595.9	1166.8	1625.7	2792.6
54	268.8	0.001299	0.0363	1171.9	2594.6	1178.9	1611.9	2790.8
56	271.1	0.001306	0.0349	1183.5	2593.3	1190.8	1598.2	2789.0
58	273.3	0.001312	0.0337	1194.7	2591.9	1202.3	1584.7	2787.0
60	275.6	0.001319	0.0324	1205.8	2590.4	1213.7	1571.3	2785.0
62	277.7	0.001325	0.0313	1216.6	2588.8	1224.8	1558.0	2782.9
64	279.8	0.001332	0.0302	1227.2	2587.2	1235.7	1544.9	2780.6
66	281.8	0.001338	0.0292	1237.6	2585.5	1246.5	1531.9	2778.3
68	283.8	0.001345	0.0283	1247.9	2583.7	1257.0	1518.9	2775.9
70	285.8	0.001351	0.0274	1258.0	2581.8	1267.4	1506.0	2773.5
72	287.7	0.001358	0.0265	1267.9	2579.9	1277.6	1493.3	2770.9
74	289.6	0.001364	0.0257	1277.6	2578.0	1287.7	1480.5	2768.3
76	291.4	0.001371	0.0249	1287.2	2575.9	1297.6	1467.9	2765.5
78	293.2	0.001378	0.0242	1296.7	2573.8	1307.4	1455.3	2762.8
80	295.0	0.001384	0.0235	1306.0	2571.7	1317.1	1442.8	2759.9
82	296.7	0.001391	0.0229	1315.2	2569.5	1326.6	1430.3	2757.0
84	298.4	0.001398	0.0222	1324.3	2567.2	1336.1	1417.9	2754.0
86	300.1	0.001404	0.0216	1333.3	2564.9	1345.4	1405.5	2750.9
88	301.7	0.001411	0.0210	1342.2	2562.6	1354.6	1393.2	2747.8
90	303.3	0.001418	0.02050	1351.0	2560.1	1363.7	1380.9	2744.6
92	304.9	0.001425	0.01996	1359.7	2557.7	1372.8	1368.6	2741.4
94	306.4	0.001432	0.01945	1368.2	2555.2	1381.7	1356.3	2738.0

96	308.0	0.001439	0.01897	1376.7	2552.6	1390.6	1344.1	2734.7
98	309.5	0.001446	0.01849	1385.2	2550.0	1399.3	1331.9	2731.2
100	311.0	0.001453	0.01804	1393.5	2547.3	1408.0	1319.7	2727.7
105	314.6	0.001470	0.01698	1414.1	2540.4	1429.5	1289.2	2718.7
110	318.0	0.001489	0.01601	1434.2	2533.2	1450.6	1258.7	2709.3
115	321.4	0.001507	0.01511	1454.0	2525.7	1471.3	1228.2	2699.5
120	324.6	0.001527	0.01428	1473.4	2517.8	1491.8	1197.4	2689.2
125	327.8	0.001547	0.01351	1492.7	2509.4	1512.0	1166.4	2678.4
130	330.8	0.001567	0.01280	1511.6	2500.6	1532.0	1135.0	2667.0
135	333.8	0.001588	0.01213	1530.4	2491.3	1551.9	1103.1	2655.0
140	336.6	0.001611	0.01150	1549.1	2481.4	1571.6	1070.7	2642.4
145	339.4	0.001634	0.01090	1567.5	2471.0	1591.3	1037.7	2629.1
150	342.1	0.001658	0.01034	1586.1	2459.9	1611.0	1004.0	2615.0
155	344.8	0.001683	0.00981	1604.6	2448.2	1630.7	969.6	2600.3
160	347.3	0.001710	0.00931	1623.2	2436.0	1650.5	934.3	2584.9
165	349.8	0.001739	0.00883	1641.8	2423.1	1670.5	898.3	2568.8
170	352.3	0.001770	0.00837	1661.6	2409.3	1691.7	859.9	2551.6
175	354.6	0.001803	0.00793	1681.8	2394.6	1713.3	820.0	2533.3
180	357.0	0.001840	0.00750	1701.7	2378.9	1734.8	779.1	2513.9
185	359.2	0.001881	0.00708	1721.7	2362.1	1756.5	736.6	2493.1
190	361.4	0.001926	0.00668	1742.1	2343.8	1778.7	692.0	2470.6
195	363.6	0.001977	0.00628	1763.2	2323.6	1801.8	644.2	2446.0
200	365.7	0.00204	0.00588	1785.7	2300.8	1826.5	591.9	2418.4
205	367.8	0.00211	0.00546	1810.7	2274.4	1853.9	532.5	2386.4
210	369.8	0.00220	0.00502	1840.0	2242.1	1886.3	461.3	2347.6
215	371.8	0.00234	0.00451	1878.6	2198.1	1928.9	366.2	2295.2
220	373.7	0.00267	0.00373	1952	2114	2011	185	2196
221.2 (Critical point)	374.15	0.00317	0.00317	2038	2038	2108	0	2108

Table B.7 Properties of Superheated Steam[a]

P(bar) (T_{sat} °C)		Sat'd Water	Sat'd Steam	Temperature (°C)→ 50	75	100	150	200	250	300	350
0.0	$\hat{H}$	—	—	2595	2642	2689	2784	2880	2978	3077	3177
(—)	$\hat{U}$	—	—	2446	2481	2517	2589	2662	2736	2812	2890
	$\hat{V}$	—	—	—	—	—	—	—	—	—	—
0.1	$\hat{H}$	191.8	2584.8	2593	2640	2688	2783	2880	2977	3077	3177
(45.8)	$\hat{U}$	191.8	2438.0	2444	2480	2516	2588	2661	2736	2812	2890
	$\hat{V}$	0.00101	14.7	14.8	16.0	17.2	19.5	21.8	24.2	26.5	28.7
0.5	$\hat{H}$	340.6	2646.0	209.3	313.9	2683	2780	2878	2979	3076	3177
(81.3)	$\hat{U}$	340.6	2484.0	209.2	313.9	2512	2586	2660	2735	2811	2889
	$\hat{V}$	0.00103	3.24	0.00101	0.00103	3.41	3.89	4.35	4.83	5.29	5.75
1.0	$\hat{H}$	417.5	2675.4	209.3	314.0	2676	2776	2875	2975	3074	3176
(99.6)	$\hat{U}$	417.5	2506.1	209.2	313.9	2507	2583	2658	2734	2811	2889
	$\hat{V}$	0.00104	1.69	0.00101	0.00103	1.69	1.94	2.17	2.40	2.64	2.87
5.0	$\hat{H}$	640.1	2747.5	209.7	314.3	419.4	632.2	2855	2961	3065	3168
(151.8)	$\hat{U}$	639.6	2560.2	209.2	313.8	418.8	631.6	2643	2724	2803	2883
	$\hat{V}$	0.00109	0.375	0.00101	0.00103	0.00104	0.00109	0.425	0.474	0.522	0.571
10	$\hat{H}$	762.6	2776.2	210.1	314.7	419.7	632.5	2827	2943	3052	3159
(179.9)	$\hat{U}$	761.5	2582	209.1	313.7	418.7	631.4	2621	2710	2794	2876
	$\hat{V}$	0.00113	0.194	0.00101	0.00103	0.00104	0.00109	0.206	0.233	0.258	0.282
20	$\hat{H}$	908.6	2797.2	211.0	315.5	420.5	633.1	852.6	2902	3025	3139
(212.4)	$\hat{U}$	906.2	2598.2	209.0	313.5	418.4	603.9	850.2	2679	2774	2862
	$\hat{V}$	0.00118	0.09950	0.00101	0.00102	0.00104	0.00109	0.00116	0.111	0.125	0.139
40	$\hat{H}$	1087.4	2800.3	212.7	317.1	422.0	634.3	853.4	1085.8	2962	3095
(250.3)	$\hat{U}$	1082.4	2601.3	208.6	313.0	417.8	630.0	848.8	1080.8	2727	2829
	$\hat{V}$	0.00125	0.04975	0.00101	0.00102	0.00104	0.00109	0.00115	0.00125	0.0588	0.0665
60	$\hat{H}$	1213.7	2785.0	214.4	318.7	423.5	635.6	854.2	1085.8	2885	3046
(275.6)	$\hat{U}$	1205.8	2590.4	208.3	312.6	417.3	629.1	847.3	1078.3	2668	2792
	$\hat{V}$	0.00132	0.0325	0.00101	0.00103	0.00104	0.00109	0.00115	0.00125	0.0361	0.0422
80	$\hat{H}$	1317.1	2759.9	216.1	320.3	425.0	636.8	855.1	1085.8	2787	2990
(295.0)	$\hat{U}$	1306.0	2571.7	208.1	312.3	416.7	628.2	845.9	1075.8	2593	2750
	$\hat{V}$	0.00139	0.0235	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.0243	0.0299
100	$\hat{H}$	1408.0	2727.7	217.8	322.9	426.5	638.1	855.9	1085.8	1343.4	2926
(311.0)	$\hat{U}$	1393.5	2547.3	207.8	311.7	416.1	627.3	844.4	1073.4	1329.4	2702
	$\hat{V}$	0.00145	0.0181	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.00140	0.0224
150	$\hat{H}$	1611.0	2615.0	222.1	326.0	430.3	641.3	858.1	1086.2	1338.2	2695
(342.1)	$\hat{U}$	1586.1	2459.9	207.0	310.7	414.7	625.0	841.0	1067.7	1317.6	2523
	$\hat{V}$	0.00166	0.0103	0.00101	0.00102	0.00104	0.00108	0.00114	0.00123	0.00138	0.0115
200	$\hat{H}$	1826.5	2418.4	226.4	330.0	434.0	644.5	860.4	1086.7	1334.3	1647.1
(365.7)	$\hat{U}$	1785.7	2300.8	206.3	309.7	413.2	622.9	837.7	1062.2	1307.1	1613.7
	$\hat{V}$	0.00204	0.005875	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00136	0.00167
221.2(P_c)	$\hat{H}$	2108	2108	228.2	331.7	435.7	645.8	861.4	1087.0	1332.8	1635.5
(374.15)(T_c)	$\hat{U}$	2037.8	2037.8	206.0	309.2	412.8	622.0	836.3	1060.0	1302.9	1600.3
	$\hat{V}$	0.00317	0.00317	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00135	0.00163
250	$\hat{H}$	—	—	230.7	334.0	437.8	647.7	862.8	1087.5	1331.1	1625.0
(—)	$\hat{U}$	—	—	205.7	308.7	412.1	620.8	834.4	1057.0	1297.5	1585.0
	$\hat{V}$	—	—	0.00100	0.00101	0.00103	0.00108	0.00113	0.00122	0.00135	0.00160
300	$\hat{H}$	—	—	235.0	338.1	441.6	650.9	865.2	1088.4	1328.7	1609.9
(—)	$\hat{U}$	—	—	205.0	307.7	410.8	618.7	831.3	1052.1	1288.7	1563.3
	$\hat{V}$	—	—	0.0009990	0.00101	0.00103	0.00107	0.00113	0.00121	0.00133	0.00155
500	$\hat{H}$	—	—	251.9	354.2	456.8	664.1	875.4	1093.6	1323.7	1576.3
(—)	$\hat{U}$	—	—	202.4	304.0	405.8	611.0	819.7	1034.3	1259.3	1504.1
	$\hat{V}$	—	—	0.0009911	0.00100	0.00102	0.00106	0.00111	0.00119	0.00129	0.00144
1000	$\hat{H}$	—	—	293.9	394.3	495.1	698.0	903.5	1113.0	1328.7	1550.5
(—)	$\hat{U}$	—	—	196.5	295.7	395.1	594.4	795.3	999.0	1207.1	1419.0
	$\hat{V}$	—	—	0.0009737	0.0009852	0.001000	0.00104	0.00108	0.00114	0.00122	0.00131

[a]Adapted from R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968. Water is a liquid in the enclosed region between 50°C and 350°C. $\hat{H}$ = specific enthalpy (kJ/kg), $\hat{U}$ = specific internal energy (kJ/kg), $\hat{V}$ = specific volume (m^3/kg). *Note:* kJ/kg × 0.4303 = Btu/lb_m.

(*continued*)

Table B.7 (Continued)

P(bar) (T_{sat},°C)		Temperature (°C)→ 400	450	500	550	600	650	700	750
0.0	$\hat{H}$	3280	3384	3497	3597	3706	3816	3929	4043
(—)	$\hat{U}$	2969	3050	3132	3217	3303	3390	3480	3591
	$\hat{V}$	—	—	—	—	—	—	—	—
0.1	$\hat{H}$	3280	3384	3489	3596	3706	3816	3929	4043
(45.8)	$\hat{U}$	2969	3050	3132	3217	3303	3390	3480	3571
	$\hat{V}$	21.1	33.3	35.7	38.0	40.3	42.6	44.8	47.2
0.5	$\hat{H}$	3279	3383	3489	3596	3705	3816	3929	4043
(81.3)	$\hat{U}$	2969	3049	3132	3216	3302	3390	3480	3571
	$\hat{V}$	6.21	6.67	7.14	7.58	8.06	8.55	9.01	9.43
1.0	$\hat{H}$	3278	3382	3488	3596	3705	3816	3928	4042
(99.6)	$\hat{U}$	2968	3049	3132	3216	3302	3390	3479	3570
	$\hat{V}$	3.11	3.33	3.57	3.80	4.03	4.26	4.48	4.72
5.0	$\hat{H}$	3272	3379	3484	3592	3702	3813	3926	4040
(151.8)	$\hat{U}$	2964	3045	3128	3213	3300	3388	3477	3569
	$\hat{V}$	0.617	0.664	0.711	0.758	0.804	0.850	0.897	0.943
10	$\hat{H}$	3264	3371	3478	3587	3697	3809	3923	4038
(179.9)	$\hat{U}$	2958	3041	3124	3210	3296	3385	3475	3567
	$\hat{V}$	0.307	0.330	0.353	0.377	0.402	0.424	0.448	0.472
20	$\hat{H}$	3249	3358	3467	3578	3689	3802	3916	4032
(212.4)	$\hat{U}$	2946	3031	3115	3202	3290	3379	3470	3562
	$\hat{V}$	0.151	0.163	0.175	0.188	0.200	0.211	0.223	0.235
40	$\hat{H}$	3216	3331	3445	3559	3673	3788	3904	4021
(250.3)	$\hat{U}$	2922	3011	3100	3188	3278	3368	3460	3554
	$\hat{V}$	0.0734	0.0799	0.0864	0.0926	0.0987	0.105	0.111	0.117
60	$\hat{H}$	3180	3303	3422	3539	3657	3774	3892	4011
(275.6)	$\hat{U}$	2896	2991	3083	3174	3265	3357	3451	3545
	$\hat{V}$	0.0474	0.0521	0.0566	0.0609	0.0652	0.0693	0.0735	0.0776
80	$\hat{H}$	3142	3274	3399	3520	3640	3759	3879	4000
(295.0)	$\hat{U}$	2867	2969	3065	3159	3252	3346	3441	3537
	$\hat{V}$	0.0344	0.0382	0.0417	0.0450	0.0483	0.0515	0.0547	0.0578
100	$\hat{H}$	3100	3244	3375	3500	3623	3745	3867	3989
(311.0)	$\hat{U}$	2836	2946	3047	3144	3240	3335	3431	3528
	$\hat{V}$	0.0264	0.0298	0.0328	0.0356	0.0383	0.0410	0.0435	0.0461
150	$\hat{H}$	2975	3160	3311	3448	3580	3708	3835	3962
(342.1)	$\hat{U}$	2744	2883	2999	3105	3207	3307	3407	3507
	$\hat{V}$	0.0157	0.0185	0.0208	0.0229	0.0249	0.0267	0.0286	0.0304
200	$\hat{H}$	2820	3064	3241	3394	3536	3671	3804	3935
(365.7)	$\hat{U}$	2622	2810	2946	3063	3172	3278	3382	3485
	$\hat{V}$	0.009950	0.0127	0.0148	0.0166	0.0182	0.197	0.211	0.0225
221.2(P_c)	$\hat{H}$	2733	3020	3210	3370	3516	3655	3790	3923
(374.15)(T_c)	$\hat{U}$	2553	2776	2922	3045	3157	3265	3371	3476
	$\hat{V}$	0.008157	0.0110	0.0130	0.0147	0.0162	0.0176	0.0190	0.0202
250	$\hat{H}$	2582	2954	3166	3337	3490	3633	3772	3908
(—)	$\hat{U}$	2432	2725	2888	3019	3137	3248	3356	3463
	$\hat{V}$	0.006013	0.009174	0.0111	0.0127	0.0141	0.0143	0.0166	0.0178
300	$\hat{H}$	2162	2826	3085	3277	3443	3595	3740	3880
(—)	$\hat{U}$	2077	2623	2825	2972	3100	3218	3330	3441
	$\hat{V}$	0.002830	0.006734	0.008680	0.0102	0.0114	0.0126	0.0136	0.0147
500	$\hat{H}$	1878	2293	2723	3021	3248	3439	3610	3771
(—)	$\hat{U}$	1791	2169	2529	2765	2946	3091	3224	3350
	$\hat{V}$	0.001726	0.002491	0.003882	0.005112	0.006112	0.007000	0.007722	0.008418
1000	$\hat{H}$	1798	2051	2316	2594	2857	3105	3324	3526
(—)	$\hat{U}$	1653	1888	2127	2369	2591	2795	2971	3131
	$\hat{V}$	0.001446	0.001628	0.001893	0.002246	0.002668	0.003106	0.003536	0.003953

Table B.8 Specific Enthalpies of Selected Gases: SI Units

$\hat{H}$(kJ/mol)
Reference state: Gas, P_{ref} = 1 atm, T_{ref} = 25°C

T	Air	O_2	N_2	H_2	CO	CO_2	H_2O
0	−0.72	−0.73	−0.73	−0.72	−0.73	−0.92	−0.84
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	2.19	2.24	2.19	2.16	2.19	2.90	2.54
200	5.15	5.31	5.13	5.06	5.16	7.08	6.01
300	8.17	8.47	8.12	7.96	8.17	11.58	9.57
400	11.24	11.72	11.15	10.89	11.25	16.35	13.23
500	14.37	15.03	14.24	13.83	14.38	21.34	17.01
600	17.55	18.41	17.39	16.81	17.57	26.53	20.91
700	20.80	21.86	20.59	19.81	20.82	31.88	24.92
800	24.10	25.35	23.86	22.85	24.13	37.36	29.05
900	27.46	28.89	27.19	25.93	27.49	42.94	33.32
1000	30.86	32.47	30.56	29.04	30.91	48.60	37.69
1100	34.31	36.07	33.99	32.19	34.37	54.33	42.18
1200	37.81	39.70	37.46	35.39	37.87	60.14	46.78
1300	41.34	43.38	40.97	38.62	41.40	65.98	51.47
1400	44.89	47.07	44.51	41.90	44.95	71.89	56.25
1500	48.45	50.77	48.06	45.22	48.51	77.84	61.09

Table B.9 Specific Enthalpies of Selected Gases: American Engineering Units

$\hat{H}$(Btu/lb-mole)
Reference state: Gas, P_{ref} = 1 atm, T_{ref} = 77°F

T	Air	O_2	N_2	H_2	CO	CO_2	H_2O
32	−312	−315	−312	−310	−312	−394	−361
77	0	0	0	0	0	0	0
100	160	162	160	159	160	206	185
200	858	875	857	848	859	1132	996
300	1563	1602	1558	1539	1564	2108	1818
400	2275	2342	2265	2231	2276	3129	2652
500	2993	3094	2976	2925	2994	4192	3499
600	3719	3858	3694	3621	3720	5293	4359
700	4451	4633	4418	4319	4454	6429	5233
800	5192	5418	5150	5021	5195	7599	6122
900	5940	6212	5889	5725	5945	8790	7025
1000	6695	7015	6635	6433	6702	10015	7944
1100	7459	7826	7399	7145	7467	11263	8880
1200	8230	8645	8151	7861	8239	12533	9831
1300	9010	9471	8922	8581	9021	13820	10799
1400	9797	10304	9699	9306	9809	15122	11783
1500	10590	11142	10485	10035	10606	16436	12783
1600	11392	11988	11278	10769	11409	17773	13798
1700	12200	12836	12080	11509	12220	19119	14831
1800	13016	13691	12888	12254	13036	20469	15877
1900	13837	14551	13702	13003	13858	21840	16941
2000	14663	15415	14524	13759	14688	23211	18019

Table B.10 Atomic Heat Capacities for Kopp's Rule[a]

Element	C_{pa}[J/(g-atom·°C)] Solids	Liquids
C	7.5	12
H	9.6	18
B	11	20
Si	16	24
O	17	25
F	21	29
P	23	31
S	26	31
All Others	26	33

[a]D. M. Himmelblau. *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition. Prentice-Hall, Englewood Cliffs, NJ, 1974. p. 270.

Table B.11 Integral Heats of Solution and Mixing at 25°C

r(mol H_2O/mol solute)	$(\Delta\hat{H}_s)_{HCl(g)}$ kJ/mol HCl	$(\Delta\hat{H}_s)_{NaOH(s)}$ kJ/mol NaOH	$(\Delta\hat{H}_m)_{H_2SO_4}$ kJ/mol H_2SO_4
0.5	—	—	−15.73
1	−26.22	—	−28.07
1.5	—	—	−36.90
2	−48.82	—	−41.92
3	−56.85	−28.87	−48.99
4	−61.20	−34.43	−54.06
5	−64.05	−37.74	−58.03
10	−69.49	−42.51	−67.03
20	−71.78	−42.84	—
25	—	—	−72.30
30	−72.59	−42.72	—
40	−73.00	−42.59	—
50	−73.26	−42.51	−73.34
100	−73.85	−42.34	−73.97
200	−74.20	−42.26	—
500	−74.52	−42.38	−76.73
1 000	−74.68	−42.47	−78.57
2 000	−74.82	−42.55	—
5 000	−74.93	−42.68	−84.43
10 000	−74.99	−42.72	−87.07
50 000	−75.08	−42.80	—
100 000	−75.10	—	−93.64
500 000	—	—	−95.31
∞	−75.14	−42.89	−96.19

[a]From J. C. Whitwell and R. K. Toner, *Conservation of Mass and Energy*, pp. 344–346. Copyright © 1969 by McGraw-Hill, Inc. Used with permission of McGraw-Hill.

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ANSWERS TO TEST YOURSELVES

p. 9

1. A ratio of equivalent values of a quantity expressed in different units.
2. $(60\ \text{s})/(1\ \text{min})$
3. $(1\ \text{min}^2)/(3600\ \text{s}^2)$
4. $(1\ \text{m}^3)/(10^6\ \text{cm}^3)$

p. 11

1. **(a)** $(1000\ \text{mm})/(1\ \text{m})$; **(b)** $(10^{-9}\ \text{s})/(1\ \text{ns})$; **(c)** $(1\ \text{m}^2)/(10^4\ \text{cm}^2)$; **(d)** $(1\ \text{m}^3)/(35.3145\ \text{ft}^3)$; **(e)** $(9.486 \times 10^{-4}\ \text{Btu/s})/(1.341 \times 10^{-3}\ \text{hp})$
2. m/s; cm/s; ft/s

p. 13

1. 2 N; $(2/32.174)\ \text{lb}_\text{f}$
2. No
3. 1 kg; same; less
4. $2\ \text{lb}_\text{m}$; same; less

p. 15

1. **(a)** 1.22×10^4 (3 s.f.); **(b)** 1.22000×10^4 (6 s.f.); **(c)** 3.040×10^{-3} (4 s.f.)
2. **(a)** 134,000 (3 s.f.); **(b)** 0.01340 (4 s.f.); **(c)** 4200 (3 s.f.)
3. **(a)** 3 s.f.; **(b)** 2 s.f.; **(c)** 3 s.f., 11.2; **(d)** 2 s.f., 12
4. **(a)** 1460; **(b)** 13.4; **(c)** 1.76×10^{-7}
5. **(a)** 4.25–4.35; **(b)** 4.295–4.305; **(c)** 2.7775×10^{-3}–2.7785×10^{-3}; **(d)** 2450–2550; **(e)** 2499.5–2500.5

p. 18

1. Breakdowns, routine or unplanned shutdowns, or installing new equipment in the second week. (Many other possibilities exist.)
2. 35.5 or 35 batches/week.
3. 40 batches/week. The second week was clearly abnormal and shouldn't influence the prediction.

p. 19

1. $\overline{V} = 237.4\ \text{cm}^3/\text{s}$, range $= 21\ \text{cm}^3/\text{s}$, $s_V^2 = 66.3\ \text{cm}^6/\text{s}^2$, $s_V = 8.1\ \text{cm}^3/\text{s}$
2. $\dot{V} = 237.4\ \text{cm}^3/\text{s} \pm 16.2\ \text{cm}^3/\text{s}$

p. 22

1. All additive terms have the same dimensions. No. Yes.
2. $\text{m}^{-2} \cdot \text{s}^{-2}$
3. A multiplicative combination of factors with no net units; st^2/r or r/st^2.
4. $a(\text{lb}_\text{f})$; Q is dimensionless.

p. 23

1. Substitute in Equation 2.7-1.
2. Correct; too high; too low; too low.

p. 27

1. $y = a(x^2 - 2)$
2. **(b)** Plot $1/y$ versus $(x-3)^2$: a = slope, b = intercept.
   (c) Plot y^3 versus x^2; a = slope, b = −intercept.
   (d) Plot $\sqrt{x/\sin y}$ versus x: a = slope, b = intercept.
   (e) Plot $\ln y$ versus x: $b = \ln(y_2/y_1)/(x_2 - x_1)$, $\ln a = \ln y_1 - bx_1$, $a = e^{\ln a}$.
   (f) Plot $\ln y$ versus $\ln x$: $b = \ln(y_2/y_1)/\ln(x_2/x_1)$, $\ln a = \ln y_1 - b \ln x_1$, $a = e^{\ln a}$.

p. 29

1. **(a)** $P = at + b$; **(b)** $P = ae^{bt}$; **(c)** $P = at^b$; **(d)** $y^2 = 3 + a\exp(b\ x^2)$; **(e)** $1/F = a(t^2 - 4)^b$.
2. **(a)** P versus t on a semilog paper;
   (b) P versus t on log paper;
   (c) P^2 versus t^3 on semilog paper;
   (d) $1/P$ (or P) versus $(t-4)$ on log paper.

p. 44

1. Dimensionless.
2. $0.50\ \text{g/cm}^3$; $2.0\ \text{cm}^3/\text{g}$; $31\ \text{lb}_\text{m}/\text{ft}^3$; 1.5 g; $36\ \text{cm}^3$
3. Yes.
4. No—possibly different reference densities used for each.
5. $\rho_{H_2O(s)} < \rho_{H_2O(l)}$; $\rho_{NBA(s)} > \rho_{NBA(l)}$
6. When T rises, the mercury in the thermometer expands. At higher temperatures the same mass thus occupies a greater volume, meaning that the density of mercury ($= m/V$) *decreases*.

p. 46

1. $10.0\ \text{cm}^3/\text{s}$
2. 159.5 g/min
3. Same; same; greater at outlet.

p. 47

1. 100 mL/min; 100 g/min
2. Flowmeters—see Figure 3.2-1.

3. Too low (the gas is much less dense, so it must flow at a much higher rate than the liquid to raise the float to the same position).

p. 49

1. **(a)** 6.02×10^{23} molecules;
   (b) M grams
2. The molecular weight of the species expressed in tons.
3. **(a)** 1 lb-mole, 2 lb_m
   (b) 2 lb-moles, 2 lb_m
4. 2000
5. 50 kmol/h

p. 52-a

1. **(a)** 80/81; **(b)** 0.5
2. 0.25 lb_m A/lb_m ; 0.75 lb_m B/lb_m ; 0.333 mole A/mole; 0.667 mole B/mole; 100 lb_m A/min; 100 lb-moles B/min; 400 lb_m/min; 150 lb-moles/min

p. 52-b

1. n/V (mol/L)
2. nM/V (g/L)
3. $(20/C_A)$ (L)
4. $(120\ c_A)$ g/h

p. 54

1. $x = 125 \times 10^{-9}$ kg C_6H_5OH/kg liquid (or g/g or lb_m/lb_m)
2. 0.125 mg C_6H_5OH
3. 125×10^{-6} g C_6H_5OH/L. (Solution density $\approx$ 1 kg/L.)

p. 56-a

1. See Figures 3.4-1 and 3.4-2 and Equation 3.4-2.
2. The fluid pressure is higher at the bottom than at the top (hydrostatic head effect). No. Maybe. Yes. (The answers depend on how large the tank is.)
3. No. Convert 1300 mm Hg to (say) dynes/cm^2, then multiply by 4 cm^2 to calculate F(dynes).
4. 79 mm Hg

p. 56-b

1. No
2. Pressure relative to a vacuum; pressure relative to atmospheric pressure.
3. 735 mm Hg (absolute); 20 mm Hg of vacuum.
4. 4 in. Hg; 33.9 in. Hg

p. 59

1. See Figure 3.4-3; 0–7000 atm; gauge.
2. See Figure 3.4-4.
3. **(a)** True; **(b)** true; **(c)** false
4. −14 mm Hg

p. 62

1. Immerse in ice–water mixture, mark mercury level as 0°. Immerse in boiling water, mark level as 100°. Divide 0 to 100 interval into 100 equal subintervals, label appropriately.
2. 1°C
3. 1°C

p. 84

1. Semibatch, transient
2. Batch, transient
3. Semibatch, transient
4. **(a)** Continuous, transient;
   (b) continuous, steady state

p. 89

3. Steady-state, either no reactions or no net mole change on reaction (e.g., A→B but not A→2B or A + B→C).
4. Steady-state, A is nonreactive.
5. Steady-state, no density change from inlet to outlet. (Good approximation for liquids and solids, effectively requires no reactions and constant temperature and pressure for gases.)

p. 93

2. $\dot{m}_T = 250(1 - x)/60$
3. $n = (75)(1.595)/(154)$
4. $\dot{m} = 50 + \dot{m}_{dg}$; $\dot{m}_{co} = 0.25\dot{m}_{dg}$; $y = 0.75\dot{m}_{dg}/(50 + \dot{m}_{dg})$

p. 95

1. $(\text{atoms})_{in} = (\text{atoms})_{out}$ for each atomic species; multiply all stream amounts by a constant factor; an assumed amount of an input or output stream.
2. **(a)** Flow rates are 1000, 20,000, and 21,000 (all kmol/h), mole fractions are unchanged.
   (b) Flow rates are 200, 100, and 100 (all lb_m/min), mass fractions are unchanged.

p. 98

1. H_2: $(5\ lb_m)_{in} = (1\ lb_m + 4\ lb_m)_{out}$; O_2: $(5\ lb_m)_{in} = (4\ lb_m + 1\ lb_m)_{out}$; total mass: $(10\ lb_m)_{in} = (10\ lb_m)_{out}$.
2. Balance on B, solve for $\dot{m}_1$; balance on C, solve for x; total mass balance, solve for $\dot{m}_2$.

p. 117

1. Yes
2. 4

3. (4 moles H_2O produced)/(6 moles O_2 consumed)
4. $(400)(6)/(4) = 600$
5. 200 mol/min

p. 119

1. C_2H_4
2. 100%
3. 50 kmol O_2; 100 kmol C_2H_4O; 50 kmol
4. 50 kmol C_2H_4; 75 kmol O_2; 50 kmol C_2H_4O; 25 kmol
5. 0.80; 0.40; 40 kmol

p. 125

1. 0.90
2. 80%
3. 16 mol B/mol C
4. 80 mol, 10 mol

p. 128

1. Three independent molecular species (C_2H_4, C_4H_8, N_2). Two independent atomic species (N and either C or H).
2. **(a)** $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
   (b) $CH_4 + \frac{3}{2}O_2 \rightarrow CO + 2H_2O$
   (c) $C_2H_6 + \frac{7}{2}O_2 \rightarrow 2CO_2 + 3H_2O$
   (d) $C_2H_6 + \frac{5}{2}O_2 \rightarrow 2CO + 3H_2O$

   Since (b) can be obtained as (a) $- \frac{1}{2}$[(c) $-$ (d)] (*verify*), the four equations are not independent.

p. 134

1. 60 mol; 0.60
2. 120 mol; 0.48
3. 40 mol CH_4 = 100 mol $CH_4 - \xi \Rightarrow \xi$ = 60 mol
   130 mol O_2 = 250 mol $O_2 - 2\xi \Rightarrow \xi$ = 60 mol
   60 mol CO_2 = 0 mol $O_2 + \xi \Rightarrow \xi$ = 60 mol
4. Four molecular species balances (CH_4, O_2, CO_2, H_2O). Three atomic species balances (C, H, O).
5. **(b)** I = O. (250)(2) mol O in = [(130)(2) + (60)(2) + (120)(1)] mol O out
   (c) I = O + C. 250 mol O_2 in = 130 mol O_2 out + 120 mol O_2 consumed
   (d) G = O. 120 mol H_2O generated = 120 mol H_2O out
   (e) I = O. (100)(4) mol H in = [(40)(4) + (120)(2)] mol H out

p. 135

1. Overall = 100/110 = 0.909 mol A consumed/mol A fed; single pass = 100/200 = 0.500 mol A consumed/mol A fed.

p. 138

1. Overall conversion = 0.833 (83.3%), single-pass conversion = 0.25 (25%).
2. Customers want B, not a mixture that contains mostly A. Makes no sense to pay for 200 mol of A (fresh feed) and then discard 140 mol of it.
3. C would keep building up in the system. Take off a purge stream from the recycle.
4. The cost of the reactor that would be required to achieve an 83.3% conversion in a single pass could be much greater than the cost of the separation and recycle equipment.

p. 145

1. 21% O_2, 79% N_2; 79/21 = 3.76 moles N_2/mole O_2
2. 25% H_2, 25% O_2, 50% H_2O; 50% H_2, 50% O_2
3. 20: 0.95; 5/95 = 0.0526

p. 146

1. 200 mol O_2/h
2. 200 mol O_2/h
3. (4.76×200) mol air/h
4. $(2 \times 4.76 \times 200)$ mol air/h
5. 50%

p. 190

1. 255 cm^3/s. If T is raised, mass flow rate remains constant but volumetric flow rate increases slightly. Look up the density of liquid water at 75°C and divide it into 200 g/s.
2. $P_h = \rho g h$, and ρ_{Hg} varies with temperature. The difference would be extremely slight.
3. $V_{tot} = \dfrac{m_1}{\rho_1} + \dfrac{m_2}{\rho_2} + \cdots + \dfrac{m_n}{\rho_n}$;

   $$\frac{1}{\rho} = \frac{V_{tot}}{m_{tot}} = \frac{m_1}{m_{tot}\rho_1} + \frac{m_2}{m_{tot}\rho_2} + \cdots = \frac{x_1}{\rho_1} + \frac{x_2}{\rho_2} + \cdots$$

p. 193

1. A relation between absolute pressure, specific volume, and absolute temperature of a substance. $P\hat{V} = RT$. High T, low P.
2. (c), (e). The mass and mass density of CO_2 are each greater by a factor $(MW_{CO_2}/MW_{H_2}) = 22$.
3. (a) and (c).

   $$\dot{V} = \frac{\dot{n}RT}{P} = \frac{\dot{m}}{MW}\frac{RT}{P}$$

   Let E denote ethylene and B denote butene. $MW_B = 2MW_E \Rightarrow \dot{V}_E = 2\dot{V}_B$.
   $\dot{V} = RT/P$, which is the same for B and E.
   Mass density: $\rho = \dot{m}/\dot{V} = (MW)P/RT \Rightarrow \rho_B = 2\rho_E$
4. RT/P = [0.08206 L·atm/(mol·K)](200 K)/(20 atm) = 0.8206 L/mol < 5 L/mol. From Equation 5.2-3, the error is likely to be greater than 1%.

p. 196

1. See Table 5.2-1.
2. $V_{new} = V_{old}/2$; $V_{new} = 2V_{old}$

3. Decreases (n is unchanged, V increases); nothing
4. (a)

p. 197

1. (b), (d)
2. 5 bar; 50 m^3; p_{H_2} increases, v_{H_2} is unchanged.
3. Greater than

p. 200

1. Vapor
2. **(a)** $P_a < P_b$; **(b)** ρ_{va} ? ρ_{vb}; **(c)** $\rho_{la} > \rho_{lb}$
3. Gas. Supercritical fluid.

p. 206

1. The equation to determine $\hat{V}$ for given values of T and P is a cubic equation.
2. Critical temperature and pressure (Table B.1), Pitzer acentric factor (Table 5.3-1).
3. (b), (a), (c)

p. 210

1. No: $T_r = (-190)/(T_c + 8)$, $P_r = 300/(P_c + 8)$, look up z on charts. calculate $V = znRT/P$.
2. Need a different chart for each species.
3. See p. 207.

p. 212

See Example 5.3-4. Nonpolar compounds with similar critical properties.

p. 238

1. Distillation. The naphthas come off from the top of the column, the lubricating oils from the bottom, and the heating oils from the middle.
2. Evaporation, filtration, centrifugation
3. Evaporation, reverse osmosis (membrane filtration at high pressure)
4. Condensation, absorption; **5.** Adsorption.

p. 243

1. −5°C, 3 mm Hg
2. −56.6°C. 5.112 atm
3. All CO_2 solidifies at 1 atm, solid melts at 9.9 atm, and −56°C, liquid boils at 9.9 atm and −40°C.
4. 1 atm; 9.9 atm
5. −78.5°C; −56°C, −40°C; **6.** No

p. 246

1. Cox chart (Figure 6.1-4); Antoine equation (Equation 6.1-4)
2. Plot p^* versus $1/T_{absolute}$ on semilog paper, draw line through points, and extrapolate to $1/T_4$.
3. The plot is more likely to be linear on the Cox chart.

p. 249

1. Eq. 6.2-1
2. **(a)** 2; **(b)** 2; **(c)** 4; **(d)** 3

p. 253

1. Yes; yes.
2. 200 mm Hg; 760 mm Hg; 200/960; look up or calculate the temperature at which $p^*_{acetone}$ = 960 mm Hg.
3. **(a)** The temperature to which a gas must be cooled before any constituent condenses; superheated, saturated.
   (b) $y_{H_2O} = p^*_{H_2O}(T_0)/P_0$ (i) nothing; (ii) condense; (iii) condense: (iv) nothing
   (c) $p^*_{H_2O}(T_{dp}) = y_{H_2O}P_0$. Look up the temperature at which the vapor pressure is $p^*_{H_2O}$.
   (d) $T_{dp} = T_0 - T_{sh}$; $y_{H_2O} = p^*_{H_2O}(T_{dp})/P_0$.

p. 254

1. 82°C
2. 50%
3. $s_m = 0.111$, $s_p = 44.4\%$

p. 258

1. Raoult's law: $p_A = x_A p^*_A$, where x_A is the mole fraction of A in the liquid phase; most likely to be valid as $x_A \rightarrow 1.0$.
2. Henry's law: $p_A = x_A H_A$; most likely to be valid when $x_A \rightarrow 0$.
3. A solution for which either Raoult's law or Henry's law is obeyed for all species at all solution compositions.
4. Henry's law for x_{CO_2} and p_{CO_2}, Raoult's law for x_{H_2O} and p_{H_2O}. Look up Henry's law constant for CO_2 (*Perry's Chemical Engineers' Handbook,* 7th Edition, p. 2-125) and vapor pressure of H_2O (Table B.3 of this book).

p. 264

1. The temperature at which the first bubble of vapor forms if the liquid is heated at the given pressure. The temperature at which the first drop of liquid forms if the vapor mixture is cooled at the given pressure.
2. 92°C; 0.70 mol benzene/mol (from Figure 6.4-1*a*)
3. 99°C; 0.30 mol benzene/mol (from Figure 6.4-1*a*); decreases
4. Increase (see Equation 6.4-4); increase (see Equation 6.4-6)
5. The hydrostatic head of the liquid must be added to the pressure at the liquid surface. Convert 5 ft of water to atm,

add it to 1 atm, and look up the boiling point of water at the corrected pressure.

6. The nonlinear equations cannot be solved explicitly for I.

p. 268

1. 380 g. The added salt will not remain undissolved.
2. 55°C. Increasing quantities of KNO_3 crystals precipitate (come out of solution).
3. See p. 267. Magnesium sulfate tetrahydrate.
4. $120.4/138.4 = 0.870$
5. Above 40°C the crystals that precipitate are hydrated salts.

p. 270

1. A solution property that depends only on concentration, and not what the solute and solvent are. Vapor pressure, boiling point, and freezing point.
2. 850 mm Hg. Solute is nonvolatile, nondissociative, and nonreactive with the solvent; Raoult's law holds.
3. Greater. $p^* = (1000 \text{ mm Hg})/0.85 = 1176 \text{ mm Hg}$.
4. It lowers the freezing point of water, so it keeps ice from forming at temperatures where it would otherwise form.
5. Antifreeze lowers the freezing point and raises the boiling point of water, so the radiator is less likely to freeze in winter and to boil in summer.

p. 273

1. See definition at bottom of p. 271. Extraction is transference of a solute from one liquid solvent to another.
2. Less soluble; $m_{VA} \gg m_W$

p. 274

1. A tie line connects compositions of two phases in equilibrium.
2. H_2O-rich phase—95.0% H_2O, 2.5% acetone, 2.5% MIBK; MIBK-rich phase—92.5% MIBK, 2.5% H_2O, 5.0% acetone. Mass ratio of MIBK phase to H_2O phase $= \dfrac{0.950 - 0.450}{0.450 - 0.025} = 1.18$.

p. 278

1. In absorption a gas species dissolves in a liquid; in adsorption a gas or liquid species adheres to the surface of a solid.
2. An adsorbate is a species adhering to the surface of a solid adsorbent.
3. Concentration equals partial pressure times a constant (and vice versa).
4. Toxic species in the air are adsorbed on the surface of the carbon. Nonactivated carbon has much less surface area so the mask would become saturated in much less time.

p. 316

1. Kinetic, potential, internal; heat, work
2. Heat is only defined in terms of energy being transferred.
3. $E_i + Q - W = E_f$

p. 318

1. The mass flow rates are the same; $\rho_{outlet} < \rho_{inlet}$; $V_{outlet} > V_{inlet}$.
2. $\Delta E_p > 0, \Delta E_k > 0$

p. 319

1. Closed system: no mass crosses system boundaries.
   Open system: mass crosses system boundaries.
   Adiabatic system: no heat transferred to or from system.
2. $Q = 250 \text{ J}$
   $W = -250 \text{ J}$
3. $\Delta U = -50 \text{ kcal}$
4. If the substance is a liquid or a solid, or a gas under nearly ideal conditions, it is reasonable to neglect the dependence of U on pressure.

p. 321

1. $\dot{V}_{in} = \dot{V}_{out}$
2. $P_{in} > P_{out}$

p. 322

1. 6000 cal
2. 1000 cal/min
3. The specific volume and pressure: $\hat{H} = \hat{U} + P\hat{V}$

p. 324

1. $\dot{W}_s = 0$
2. $\dot{Q} = 0$
3. $\Delta \dot{E}_k = 0$
4. $\Delta \dot{E}_p = 0$

p. 327

1. A property whose change of value in any process depends only on its initial and final states and not on the path between them.
2. **(a)** 0;
   (b) 5000 J/kg;
   (c) $\Delta \hat{H} = \hat{H}_A(\text{v}, 0°\text{C}, 1 \text{ atm}) - \hat{H}_A(\text{v}, 30°\text{C}, 1 \text{ atm})$
   $= (5000 \text{ J/kg} - 7500 \text{ J/kg}) = -2500 \text{ J/kg}$
   (e) No—$\hat{H}$ is a state property.

p. 337

1. Incompressible fluid, negligible heat transfer, and no internal energy changes due to anything but friction.
2. Above, plus no friction or shaft work.

p. 359

$\hat{H} = -2751$ kJ/kg. $\hat{U} = -2489$ kJ/kg.

p. 361

2. Lower P isothermally to 1 atm, cool at 1 atm to 80.7°C, condense at 80.7°C and 1 atm, cool liquid at 1 atm to 25°C, raise pressure to 5 atm.
3. Keeping pressure constant at 1 atm, cool water to 25°C, dissolve NaOH in water at 25°C, raise solution to 50°C.
4. Keeping pressure constant at 1 atm, cool O_2 to 25°C, mix O_2 and CH_4 at 25°C, carry out reaction at 25°C, raise product gas to 300°C.

p. 366

1. **(a)** ii; **(b)** i; **(c)** iii
2. Determine z for C_2H_6 at each of the system conditions. If z is close to 1 for both states, it may be reasonable to neglect $\Delta\hat{H}$.

p. 368

1. $C_v = (\partial\hat{U}/\partial T)_v$,
   $C_p = (\partial\hat{H}/\partial T)_P$
2. **(a)** exact;
   (b) inaccurate;
   (c) good approximation
3. $\Delta H = (5\text{ g})[0.5\text{ cal/(g·°C)}](20°\text{C}) = 50$ cal

p. 371

1. 28.5 J/(mol·°C)
2. 5 cal/(mol·°C); 7 cal/(mol·°C)
3. **(a)** 22.44 kJ/mol;
   (b) −25.78 kJ/mol;
   (c) -2.22×10^5 Btu/h (Neglect pressure effects.)

p. 373

1. $CaCO_3(s)$: $C_p = 26 + 7.5 + 3(17) = 84.5$ J/(mol·°C)
2. $\Delta H = \{(2\text{ kg})[2.5\text{ kJ/(kg·°C)}]$
   $+ (1\text{ kg})(1.8\text{ kJ/(kg·°C)})\}(10°\text{C}) = 68$ kJ
   $\Delta\hat{H} = 68\text{ kJ}/3\text{ kg} = 23$ kJ/kg
3. $\Delta\hat{H} = 25$ cal/g
4. $(C_p)_{\text{mixture}} = [(0.50)(1.00) + (0.50)(0.54)]$ cal/g = 0.77 cal/g

p. 381

1. Yes; no
2. **(a)** 0; **(b)** 900 J/mol
   (c) Cool the vapor to 75°C; condense at 75°C; cool the liquid to 25°C.
3. $\Delta\hat{U}_f \approx 5500$ cal/mol
   $\Delta U_v = \Delta\hat{H}_v - RT = 26{,}710$ cal/mol

p. 382

1. Equation 8.4-3
2. Equation 8.4-4
3. From Equation 8.4-6, slope of line is $-\Delta\hat{H}_v/R$.
4. From Equation 8.4-7, slope of tangent to curve at $p^* = 1$ atm is $-\Delta\hat{H}_v/R$.
5. Equation 8.4-8
6. $\Delta\hat{H}_v(T_2) = \int_{T_2}^{T_1} C_{pl}\,dT + \Delta\hat{H}_v(T_1) + \int_{T_1}^{T_2} C_{pv}\,dT$

p. 392

Air at 25°C, $h_r = 20\% \Longrightarrow h_a = 0.0040$ kg H_2O/kg dry air;
$T_{wb} = 12.5°\text{C}$; $T_{dp} = 0.5°\text{C}$; $\hat{V}_H = 0.85$ m³/kg dry air,
$\hat{H} = (35.00 - 0.27)$ kJ/kg dry air $= 34.73$ kJ/kg dry air

p. 395

1. **(a)** $(C_p)_{gas}$, $(C_p)_{liquid}$, and $(\Delta\hat{H}_v)_{liquid}$ are independent of temperature, and the enthalpy change of unevaporated liquid is small compared to the heat of vaporization and the enthalpy of the gas.
   (b) Yes; **(c)** no
2. $T_{as} = 11°\text{C}$; $h_a = 0.0069$ kg H_2O/kg dry air;
   $h_r = 70\%$; $\hat{H} = (31.60 - 0.06)$ kJ/kg dry air $= 31.54$ kJ/kg dry air

p. 397

1. **(a)** $\hat{H} = -40$ kJ/mol A; **(b)** $\hat{H} = 20$ kJ/mol A
2. $Q = \Delta H = (5)(-40)$ kJ $= -200$ kJ (evolved)
3. $Q = 5(-60 + 40)$ kJ $= -100$ kJ (evolved)

p. 402

1. −97 Btu/lb_m solution
2. 77°F (the reference temperature for H_2SO_4)
3. 190°F. 65 wt% H_2SO_4. (Highest temperature on a line between the feed points.)
4. **(a)** −60 Btu/lb_m solution. **(b)** 30 Btu/lb_m solution. The heat of solution at 77°F (or the energy required to heat the solution from 77°F to its adiabatic mixing temperature of about 195°F).

p. 406

1. 130°F, 0.15
2. 600 Btu/lb_m
3. Vapor fraction $\approx (0.50 - 0.18)/(0.88 - 0.18) = 0.46$

p. 441

2. The second sentence is wrong and the first sentence is correct, but only if the reactants and products are at the same temperature. The energy released by the breaking of reactant bonds and forming of product bonds must be transferred from the reactor to keep the products at the

same temperature; otherwise it remains in the reactor and raises the product temperature. If the reactor is adiabatic, the products at the higher temperature would be at the *same* energy level as the reactants at the lower temperature.

p. 445

1. $H_{\text{products}} - H_{\text{reactants}}$ when stoichiometric quantities of reactants are fed, the reaction proceeds to completion, and reactants and products are at the same temperature and pressure. As above, with reactants and products at 25°C and 1 atm.
2. **(a)** −20 kJ/mol A reacted; **(b)** exothermic; **(c)** withdrawn; **(d)** higher
3. The latent heat of vaporization of C_6H_{14} at 25°C and 1 atm
4. $\Delta\hat{U}_r(T) = \Delta\hat{H}_r(T) + 2RT$
5. $\Delta\hat{H}_r = \sum_{\text{products}} |v_i|\hat{H}_i - \sum_{\text{reactants}} |v_i|\hat{H}_i$

   In general, $\hat{H}_i = \hat{U}_i + P\hat{V}_i$; for liquids and solids, $\hat{H}_i \approx \hat{U}_i$; and for ideal gases, $P\hat{V}_i = RT$, so that $\hat{H}_i = \hat{U}_i + RT$. To obtain the desired result, substitute for $\hat{H}_i$ in the expression for $\Delta\hat{H}_r$, and recognize that

$$\Delta\hat{U}_r = \sum_{\text{products}} |v_i|\hat{U}_i - \sum_{\text{reactants}} |v_i|\hat{U}_i$$

p. 447

1. See last paragraph of Section 9.2.
2. Multiply Equation 2 by −2 and add the result to Equation 1

   $2A + B - 2A - 2D \rightarrow 2C - 2C - 6E$

   $\Downarrow$

   $B + 6E \rightarrow 2D$, $\Delta\hat{H}_r = \Delta\hat{H}_{r1} - 2\Delta\hat{H}_{r2} = 3000$ kJ/mol

p. 448

1. The formation reaction of CO is $C + \frac{1}{2}O_2 \rightarrow CO$, so the heat of formation is $-\frac{1}{2}$ times the heat of the given reaction, or −110.5 kJ/mol. (This checks with the value in Table B.1.)
2. The heat of vaporization of propane at 25°C.
3. $\Delta\hat{H}_r^\circ = (\Delta\hat{H}_f^\circ)_{CO_2} + 2(\Delta\hat{H}_f^\circ)_{H_2O(v)} - (\Delta\hat{H}_f^\circ)_{CH_4}$

p. 464

1. **(a)** $\Delta\hat{H}_f^\circ(\text{soln}, n = 50) = (\Delta H_f)_A - 100 - 10$
   $= -110$ kJ/mol A
   (b) $\Delta\hat{H}_f^\circ(\text{soln}, n = \infty) = -115$ kJ/mol A
2. **(a)** $\hat{H}(25°C) = -110$ kJ/mol A
   (b) $H(25°C) = -550$ kJ

p. 466

1. $LHV = 2658$ kJ/mol
   $HHV = 2658$ kJ/mol + 5(44.013 kJ/mol)
   $= 2878$ kJ/mol
2. $HHV = (0.40)(143\text{ kJ/g}) + (0.60)(55\text{ kJ/g})$
   $= 90.2$ kJ/g
3. For coal:

   $(\$150/\text{ton})(1\text{ lb}_m/15{,}000\text{ Btu})(1\text{ ton}/2000\text{ lb}_m)$
   $= 5.0 \times 10^{-6}$ \$/Btu

   For natural gas:

   $x(\$/\text{ton})(1\text{ ton}/2000\text{ lb}_m)(1\text{ lb}_m/23{,}000\text{ Btu})$
   $= 5.0 \times 10^{-6}$ \$/Btu

   $\Downarrow$

   $x = \$230/\text{ton}$

p. 469

1. The product temperature when the fuel is burned completely in an adiabatic reactor.
2. Heat loss through reactor walls, incomplete reaction.
3. With an air feed, the heat released from combustion of a fixed amount (say, 1 mol) of fuel goes into heating the nitrogen in the air as well as the reaction products and excess oxygen, whereas only the latter must be heated for a pure O_2 feed. If a fixed quantity of heat is added to a greater amount of material, the resulting temperature rise must be less.

p. 471

1. **(a)** Ignition—abrupt increase in the rate of an oxidation reaction.
   (b) Ignition temperature—the temperature at which ignition occurs when a combustible mixture is heated slowly.
   (c) Ignition lag—time between a mixture reaching its ignition temperature and the occurrence of ignition.
   (d) Flammability limits—composition limits outside of which ignition or explosion cannot occur.
   (e) Flash point of a liquid—temperature at which a liquid gives off enough vapor to form an ignitable mixture with the air above the liquid surface.
2. **(a)** An explosion or ignition; no reaction would occur.
   (b) Yes; the reaction would cease.
   (c) There is a region between the emerging jet (pure methane) and the bulk of the room air (almost no methane) within which the methane fraction falls between the flammability limits. The flame persists in this region.

p. 473

1. A flame is a combustion zone in which various species undergo transitions from states of high energy to states of lower energy. The energy lost in the transitions is given off as visible light.
2. In low-temperature flames, which occur when the fuel and oxygen are not well mixed, carbon particles are formed

and remain unburned, but the heat in the reaction zone raises them to a temperature at which they glow incandescently. The result is a yellow flame. At higher combustion temperatures, various intermediate species are formed and excited to high-energy states, and emit blue light as they return to lower states. The result is a blue flame.

3. In a detonation, a pressure front (shock wave) forms and propagates at supersonic speed, rapidly compressing and igniting the flammable mixture and giving the appearance of an instantaneous combustion. In the vicinity of the detonation, the force of the shock wave can demolish a building or propel a bullet. The noise is the vibration of the eardrums caused by the shock wave.

4. The rate of the reaction depends strongly on temperature; at room temperature it is immeasurably low.

p. 507

1. **(a)** 1; **(b)** x_1

2. Ten variables (flows of A, B, C, and D at inlet, A, B, and C in vapor product, and B, C, and D in liquid product) − 4 balances (A, B, C, and D) − 2 relations (given split of B, equilibrium relation for C) = 4 degrees of freedom.

p. 510

1. Mixer—3, separator—4

2. 5 degrees of freedom (7 local degrees of freedom − 2 ties)

p. 548

1. **(a)** Accumulation, input, output (although the mass balance will yield the result that accumulation = 0);
   (b) all but generation;
   (c) accumulation, output, consumption

2. $dm/dt = 10\ \text{kg/h} - 10\ \text{kg/h} = 0\ \text{kg/h}$

p. 551

1. $$dy = (2-t)\,dt \Longrightarrow \int_1^y dy = \int_0^t (2-t)\,dt$$
$$\Longrightarrow y = 1 + 2t - \frac{t^2}{2}$$

2. $$\frac{dy}{2-y} = dt \Longrightarrow \int_1^y \frac{dy}{2-y} = \int_0^t dt$$
$$\Longrightarrow -\ln(2-y)\Big]_1^y = t$$
$$\Longrightarrow \ln\left(\frac{1}{2-y}\right) = t$$
$$\Longrightarrow \left(\frac{1}{2-y}\right) = e^t$$
$$\Longrightarrow y = 2 - e^{-t}$$

3. $$\frac{dy}{2-y} = (2-t)\,dt \Longrightarrow \int_1^y \frac{dy}{2-y} = \int_0^t (2-t)\,dt$$
$$\Longrightarrow -\ln(2-y)\Big]_1^y = 2t - \frac{t^2}{2}$$
$$\Longrightarrow \ln\left(\frac{1}{2-y}\right) = 2t - \frac{t^2}{2}$$
$$\Longrightarrow \left(\frac{1}{2-y}\right) = \exp\left(2t - \frac{t^2}{2}\right)$$
$$\Longrightarrow y = 2 - \exp\left(-2t + \frac{t^2}{2}\right)$$

p. 560

1. Neglect changes in $\dot{E}_k$ and $\dot{E}_p$; no mass accumulation; $\hat{U}$ and $\hat{H}$ independent of P; no phase changes or chemical reactions; no spatial variations in Γ; constant C_v and C_p.

2. When the expression for U_{sys} is differentiated to yield Equation 11.3-9, if C_v varies with temperature (and hence with time) another term of the form $M(T_{sys} - T_r)(dC_v/dt)$ would have to be added.

p. 609

1. $-1, +2$

2. The line for which the sum of the squares of the residuals is a minimum.

3. Yes. (Corollary—no.)

4. Positive and negative deviations from the line would cancel out, possibly making a terrible fit look good.

p. 611

1. Linear

2. Nonlinear

3. Nonlinear

4. **(a)** Linear; **(b)** nonlinear

5. **(a)** Linear (multiply equation by z); **(b)** nonlinear;
   (c) linear

p. 612

1. A straight line on a plot of f versus x can only intersect the x axis at one point.

2. One root. (The intersection of a 45° line through the origin with a curve that begins at 1 when $x = 0$ and decreases, approaching 0 as x approaches infinity.)

p. 613

1. **(a)** $x = 4$ and $x = 0$; **(b)** $x_p = 15/4$; $x_n = 5$. Converge to $x = 4$.

2. The equation for a line on an f versus x plot through (x_n, f_n) and (x_p, f_p) is $f = f_n + [(f_p - f_n)/(x_p - x_n)](x - x_n)$. The intercept of this line on the x axis, which we will call x_{new}, is obtained by setting $f = 0$

and solving the resulting equation for x. The result is Equation A.2-1.

p. 615

1. Yes. No. You can solve for the roots directly.
2. The value of $f'(x_0)$ would be 0, and the correction term f/f' would blow up.

p. 617

1. **(a)** Modified successive substitution; **(b)** successive substitution; **(c)** acceleration
2. 13.6

p. 618

1. 2.60
2. A line on an f versus x plot through (2, 2.3) and (2.3, 2.45) intersects the 45° line at $x = 2.60$.

p. 626

1. 80
2. 84
3. 80. The function is cubic, so Simpson's rule is exact.

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ANSWERS TO SELECTED PROBLEMS

CHAPTER TWO

2. **(c)** 120 hp

6. 4.3×10^5 miles

8. **(b)** 2.6 kg

10. 25 m^3

14. **(b)** 0.135 m/s^2

18. **(a)** $s_T = 2.3°C$

20. **(a)** $s_X = 2.2$

24. **(a)** 88.8 cm/s (or 0.888 m/s)

26. **(b)** 1.13 g/cm^3

28. **(b)** $t(C = 0.1 \text{ mol/L}) = 1.12$ min (extrapolated), 1.70 min (exact)

30. **(d)** $xy = 2e^{3y/x}$

32. **(b)** 109 kg/h

34. **(a)** $k = 9.3 \times 10^{-3}$ min^{-1}

36. $k = 1.573$ (dimensionless). Answer may vary slightly.

38. **(b)** Runs 1, 2, 3, 4 $\Rightarrow b = 0.52$. Answer may vary slightly.

40. **(c)** $t = 209.5$ h

42. **(b)** For Lab 1, $k = 0.0062$ s^{-1}

44. $a = 6.536$

CHAPTER THREE

2. **(b)** 360 lb_m/ft^3

4. $68.42 in France

6. **(a)** 445 L

8. $(SG)_{solution} = 1.5$

10. **(b)** 1.00×10^3 N

12. **(b)** 4.6 kg Ile/h

14. **(f)** 1.08×10^6g C

16. **(b)** 8715 lb_m/h

18. 0.300 g $CaCO_3$/g suspension

20. **(c)** 3.84×10^{-5} kg $CaSO_4$

22. **(a)** $SG = 0.903$

24. 0.917 g/cm^3

26. **(a)** Sample 1: 15.6 mole% CH_4, 6.2 wt% CH_4

28. **(c)** 87.7 s

30. 0.155 g

32. **(e)** 0.737 atm

36. $P = 32.9$ psi

38. **(b)** $F_{min} = 2.0 \times 10^5$ N

40. $P_{atm} = 775$ mm Hg

42. **(a)** $h = 400 \text{ cm} \Rightarrow R_{water} = 646$ cm

44. **(b)** 6.54 psig

46. **(a)** 393 mm Hg

48. **(c)** 153°F

50. **(b)** 3.26°C/s

52. **(b)** 2.6 lb_m CO

54. At 94°C, $k = 0.707$ L/(mol · min)

CHAPTER FOUR

4. **(d)** $x_{O_2} = 0.21\, n_2/(n_1 + n_2)$

6. **(b)** Two unknowns must be specified

8. **(c)** .22 (22%) of the large eggs are broken

10. 207 gal.

12. **(b)** 5.80×10^3 mol CH_3OH/h

14. **(a)** 6480 lb-moles/h

16. **(b)** 2.96 L 20% solution/L 60% solution

18. **(b)** $\$8.8 \times 10^7$/year

20. **(a)** 1.2×10^{-3} mol $H_2O(v)$/mol

22. **(c)** $x_P = 0.20$, $m_P = 100.0 \Rightarrow n_A = 3.29$, $n_B = 1.10$

24. **(b)** velocity = 8.33 m/s

26. **(c)** 423 kg SO_2/min removed from feed gas

28. 3 balances on overall system, 2 on Unit 1

30. **(c)** 39.8% salt in the effluent from the 4th evaporator

32. **(b)** 28.6 kg of 42% concentrate

34. **(b)** Recycle ratio = 1.60

36. **(b)** 9.71 kg C_6H_{14} recycled/kg C_6H_{14} fed

38. **(c)** 3796 kg steam fed to stripper

40. **(c)** 17.6% excess NH_3

42. $\dot{\xi} = 56.2$ mol/s

44. 7380 kg 80% H_2SO_4

46. **(b)** $X_A = X_B = 0.688$

48. **(c)** $X_{CO} = 0.156$

50. **(c)** Fractional yield of $C_2H_5Cl = 0.875$

52. 1533 kg ore

54. For the 1st feed mixture, $y_A = 0.2027$, $y_E = 0.0393$

56. **(b)** CH_3OH enters the reactor at the rate of 50.0 kmol/h

58. **(c)** 85.9 kmol/h recycle

60. **(a)** S.P. Conversion = 14%

62. **(b)** 2.535×10^4 kmol/h n-C_4H_{10} in emulsion recycle, 2220 kmol H_2SO_4/h and 1200 kmol H_2O/h in acid recycle, 1040 kmol i-C_4H_{10}/h recycled from distillation column

64. **(b)** 66.5 kmol/h
66. 250 kmol/h
68. **(b-iii)** 9.1 mole% CO_2
70. **(c)** 18.6% excess air
72. **(a)** Desired percent excess air = 11%
74. 10.7% CO_2, 9.8% H_2O
76. **(b)** 3.72×10^5 mol air/tonne coal
78. 30% bypass
80. **(b)** Minimum percent excess air = 117%.

CHAPTER FIVE

2. Bulk density = 3.26 g/cm^3
4. **(c)** 35.4 kg $CuSO_4$ (anhydrous)
6. **(b)** 9.3% error
8. **(b)** 555
10. 165 m/s
12. Unknown MW = 3.9
14. **(a)** 880 cm^3/s
16. 71.2%
18. 1.52
20. **(c)** 58.5 g/L
22. **(a)** y_B (9 am) = 0.62×10^{-6}
24. **(b)** \$1,747,000/month
26. **(b)** 3595 mol diluting air/s
28. **(b)** 3.3 cm H_2O
30. 4.0×10^4 m^3(STP) air/h
32. **(a)** 346 kPa
34. **(c)** 1.2×10^5 Å
36. **(b)** $x = 0.5 \Rightarrow V = 2.16 \times 10^4$ L
38. **(b)** 71% conversion of propylene
40. **(b)** 196 kg acetone vaporized/h
42. 0.150 mol Cl_2/mol
44. 1.8% Fe_2O_3
46. **(a)** 4.08×10^5 L gas/min leaves the condenser
48. **(b)** f_{SO_2} = 0.367 at 600°C
50. 846 SCMH recycled
52. 25.7 mole% CO_2, 6.5% CO, ...
54. **(a)** Reactor effluent (C): 49.4 kmol/h, 26% H_2, 53% CH_3OH, 0.03% H_2O
56. 135 m^3/h
58. P_{SRK} = 7.3 atm
60. 1.57×10^4 L/h
62. **(b)** 37.4 lb_m
64. **(b)** $z = 1.6$
66. 320°F
68. 74.3 mol
70. **(b)** $P > 2.1 \times 10^4$ atm **(c)** 5 cycles
72. **(b)** 34,900 gallons
74. 0.041 m^3
76. 126 ft^3/min
78. **(b)** 29.9 m^3/h
80. 1.63 kmol/min
82. **(b)** $C_{11}H_{20}O_{10}$

CHAPTER SIX

2. **(b)** 0.235 g vapor/g total
4. 58.8 kJ/mol
6. T_b = 116°C
8. 8.0×10^{-4} mol
10. **(b)** 6.85°C
12. **(b)** 99.7% condensation
14. At 70°F and 50% r.h., ρ_{air} = 1.196 g/L
16. 5.04×10^4 ft^3/min
18. 0.310 m^3 outlet air/m^3 feed air
20. **(c)** 0.479 lb-mole octane lost
22. **(c)** 2.52°C
24. **(b)** 29°C
26. **(b)** 96% recovery if the refrigerant is used
28. 1.81 gal. condensed/min
30. **(b)** Cool to 7.8°C
32. **(a)** 0.0148 kmol CH_3OH/min
34. $\dot{V}_{in} = 2.09 \times 10^5$ ft^3/h
36. **(b)** $\dot{V}_{inlet}$ = 2590 ft^3/h
38. T_{dp} = 58.8°C
40. **(b)** x = 0.00536 mol C_3H_8/mol
42. **(a)** 1097 mol leave converter, 15.5% H_2O
44. **(b)** 8.33×10^{-2} m^3 gas feed/kg liquid feed
46. 0.0711 mol benzene/mol
48. $x_{CH_4} = 1.46 \times 10^{-4}$ mol CH_4/mol
50. **(c)** 127 cm^3
52. 85.85°C
54. **(a)** P = 76 psig
56. **(a)** 0.096 mol C_6H_6/min
58. **(b)** 22.6% benzene $\Rightarrow T_{bp}$ = 108.1°C
60. **(d)** 0.39 m
62. **(d)** $x_B = 0.400 \Rightarrow y_B = 0.795$, P = 444 mm Hg
66. **(c)** 0.46 mol vapor/mol liquid
68. **(d)** 64.5°C
70. 79.9°C

72. **(c)** 0.19 lb-mole H_2O/lb-mole

74. 32.3%

76. **(c)** 23.0 kg A

78. 0.428 lb_m crystals/lb_m liquid

80. 2044 kg/h recycled

82. **(c)** 64 lb_m recycle/lb_m fresh feed

84. $T_m = 1.9°C$

86. 83.5 g/mol, 6.38 kJ/mol

88. 4.4 g styrene in ethylene glycol phase

90. **(a)** The extraction requires 13,000 kg of hexane

92. **(b)** 0.2965 kg alkaline solution/kg acidified broth

94. Water-rich phase: 21% acetone, 3% MIBK, 76% water (answers may vary)

96. **(c)** For System 2, $\beta_{aw} = 41.8$ (answers may vary)

98. **(a)** 33.1 grams of silica gel

100. **(b)** 1.13 hours (68 minutes)

CHAPTER SEVEN

2. **(b)** 3000 MW

4. **(a)** $\dot{E}_k = 1.40 \times 10^{-5}$ hp

6. **(b)** $u = 25.4$ ft/s

8. $\dot{E}_{max} = 3.43 \times 10^6$ kW · h/wk

10. **(b)** $Q = -765$ J

12. 2338 J/mol

14. 9.0×10^3 cal

16. **(a)** (i) 941 cm^3, (ii) 19.5 J, (iii) 64.3 J

18. **(c)** $\Delta\dot{E}_p = -\dot{W}_s, \dot{W}_s > 0$

20. **(a)** 246 L/s

22. 477 m/s

24. **(a)** 6.02×10^7 J/s

26. 5.80×10^4 kW

28. **(b)** 1.27 m^3 steam/s

30. **(a)** 300 kJ/h

32. **(b)** 1.8 kW

34. **(a)** Every 13 seconds

36. **(a)** 0.296 evaporates

38. **(b)** 2920 kJ/s

40. 587 kJ/h

42. **(a)** 1.82×10^4 cal

44. **(c)** 5.70×10^4 kJ

46. 38 g

48. **(a)** 0.53 g evaporated

50. 2.6 g evaporated

52. **(a)** 0.894 m/s

54. **(a)** 122 L/min

56. 76.2 m^3/min

58. 0.62 kW

CHAPTER EIGHT

2. **(c)** $\Delta\hat{U} = 2160$ J/mol

4. **(d)** 31.71 kJ/mol

6. **(c)** −110.7 kJ/mol

8. 7193 kW

10. **(b)** $C_p \approx 0.223$ kJ/(mol · K)

12. **(c)** Total daily cost = $4.72

14. **(a)** −2156 kW

16. 1833 Btu/h

18. −0.07643 kJ/g

20. 1810 m^2

22. **(c)** 3.41 m^3/s

24. **(c)** 0.400 m^3 steam/m^3 propane

26. **(b)** Relative humidity = 79.7%

28. 1.39×10^6 J/day

30. **(b)** 290 kW

32. **(a)** 792°C

34. $\Delta\hat{H}_{analytical} = -1730$ cal/g

36. **(c)** 60.12 kJ/mol

38. -1.90×10^4 kW

40. **(a)** 1.95×10^5 kJ/h

42. $\Delta\hat{H}_v(100°C) \approx 38.2$ kJ/mol

44. **(c)** 33.4 kJ/mol

46. **(d)** −181 kJ/m^3 air fed

48. 733 kW

50. **(b)** 257 kW

52. **(a)** 2.42×10^4 kW

54. **(d)** $T_{f2} = 34°C \Longrightarrow T_{a1} = 504.6°C$

56. **(b)** 163 kg/h additional steam

58. **(c)** 3733 kg/h fresh water

60. **(c)** 0.51 g evaporate

62. **(a)** 1760 kW

64. **(d)** 1.16×10^5 kJ/h

66. **(b)** $x_F = 0.5, T_f = 110°C$, $P = 760$ mm Hg $\Longrightarrow T_{evap} = 52.2°C$

68. **(a)** 0.840 kg steam generated, 973 kJ transferred from condenser

70. $T_{dp} = 77.3°F, \hat{H} = 43.9$ Btu/lb_mDA

72. **(d)** $Q = -31$ J

74. **(b)** 2.9 tons of cooling

76. **(b)** 0.0119 kg H_2O added/min

78. **(b)** 67 m^3

80. **(b)** −15.5 kW
82. **(b)** 11.09 kJ/mol HCl
84. 6.09×10^4 J/mol H_2SO_4
86. **(b)** −471 kJ/L product
88. **(b)** 291.4 g $H_2O(l)$, 547.3 g $H_2O(s)$
90. **(c)** 60 kJ/h transferred from the crystallizer
92. **(b)** T_{max} = 125°C
96. **(b)** 140°F
98. Liquid: 10.5 g NH_3, 64.5 g H_2O

CHAPTER NINE

2. **(c)** -1.53×10^5 kW
4. **(c)** +122 kJ
6. **(a)** 122.7 kJ/mol
8. **(c)** -1.26×10^5 kJ/h (evolved)
10. **(b)** $\Delta\hat{H}_c^\circ = -5068$ kJ/mol
12. **(c)** $\dot{Q} = -0.0536$ kW
14. **(c)** $Q = 251$ kJ
16. **(b)** 1350 kW
18. **(c)** $Q = 11.863$ kJ
20. **(b)** −81.5 kW
22. **(b)** -6.44×10^4 Btu/h
26. **(c)** −279 kW (process), −265 kW (reactor)
28. **(b)** **A:** 3.67×10^5 kJ/h, **F:** 1.34×10^6 kJ/h, **C:** 5.65×10^4 kJ/h
30. **(c)** 55.9 kmol recycled/h
32. **(a)** 80.1% conversion
34. **(b)** 59.2 kJ/mol feed
36. **(a)** 0.417 mol C_2H_4/mol CH_4 consumed
38. **(c)** $n_0 = 9.0$ mol O_2
40. −55.0 kJ/mol, −177.9 kJ/mol
42. **(a)** $\Delta\hat{H}_f^\circ = 222.4$ kJ/mol
44. **(a)** 177 kJ/mol $(NH_4)_2SO_4$
46. **(a)** 94°C
48. **(a)** LHV = 843 kJ/mol
50. 72.5% CH_4, 18.8% C_2H_6, 8.7% CO
52. **(a)** 2.5 gal/h
54. **(b)** 40.3 kJ. 534 kJ
56. **(b)** 2.13×10^4 kJ/m^3 fuel
58. **(c)** −655 kW
60. **(b)** 1.16×10^5 kg steam/h
62. **(a)** 99% excess air
64. **(b)** 2780°C
66. **(a)** 1832°C
68. **(d)** For Run 2, T_{ad} = 1738°C
70. **(a)** $\dot{m}_B = 30.3$ tonnes/d, $\dot{m}_F = 11.2$ tonnes/d, $\dot{Q}_1 = 8.04 \times 10^7$ kJ/d, $\dot{Q}_4 = 1.38 \times 10^7$ kJ/d

CHAPTER TEN

2. **(b)** $n_1, n_2, n_3, x_1, x_2, x_3$
4. **(a)** 7 degrees of freedom
6. **(b)** 1.80 mol recycle/mol fresh feed
10. **(c)** For the given conditions, $\dot{Q} = -23.7$ kW
12. **(b)** T = 1560°C

CHAPTER ELEVEN

2. **(a)** $n_p' = 0.3743$, $n_p(0) = 7.5$
4. **(d)** $t = 120$ s, $n_{O_2} = 0.30$ lb-mole
6. **(d)** 26.5 min.
8. **(d)** C_{SO_2} (2 min.) $= 3.82 \times 10^{-7}$
10. **(e)** 90% conversion at $t = 4.6$ min.
12. **(c)** 20.6 seconds
14. **(b)** 3.5×10^{-3} min^{-1}
16. **(b)** $k_2 = 0.115$ L/mol
18. **(b)** 2.7 hours
20. **(b)** 4.29 kW
22. **(c)** $T_b = 30°C \Rightarrow t = 100$ min
24. **(b)** 200 g
26. **(b)** 54.8°C
28. **(a)** $dC_{S2}/dt = 0.080(C_{S1} - C_{S2})$
30. **(c)** $dx/dt = -(\dot{n}_V/N_L)[-x + ax/(x + b)]$

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The accompanying CD

—INTERACTIVE CHEMICAL PROCESS PRINCIPLES (ICPP)—

is a guide and toolkit for students using this text in an introductory chemical engineering course. It also contains reference materials that should be useful throughout the chemical engineering curriculum.

ICPP HAS THE FOLLOWING COMPONENTS:

Index of Learning Styles A student's learning style is the way the student tends to take in and process information. The Index of Learning Styles (ILS) is a 44-item questionnaire used to assess preferences on four learning style dimensions (active/reflective, sensing/intuitive, visual/verbal, and sequential/global). By completing this questionnaire, you can get information about your learning style preferences, which in turn suggests the types of teaching and studying that work well for you and the types that don't. We also offer suggestions for the most effective way to use this CD based on your learning preferences. We suggest you complete this questionnaire and make use of the results early in your course studies.

Instructional Tutorials This section of ICPP contains six instructional tutorials, each designed to be worked through at a different point of the introductory course. The tutorials describe systems, pose problems, and guide you through the solutions. There are several ways to approach the tutorials. The easy way, and the least valuable, is simply to look for the answers rather than attempt to solve the problems. The only way to get the full benefit of the tutorials is to try to solve the problems yourself first, and then to check yourself by looking at the correct solutions.

Visual Encyclopedia of Chemical Engineering Equipment Many of the problems in the text make reference to common chemical process equipment, such as heat exchangers, pumps, separation process units (absorption towers and distillation columns), and various types of chemical reactors. In most cases, you won't have to know how these various pieces of equipment work to solve the problems, but you may avoid confusion by getting a good picture of how they work before you begin the analysis. By clicking on the equipment type in the Visual Encyclopedia (developed by Professor Susan Montgomery and her students at the University of Michigan and distributed by permission from The Regents of the University of Michigan), you will obtain a photograph and/or a cutaway view of the equipment item, along with a short description of how it works and where in the chemical industry it tends to be used. Note: The CD must be in the CD drive in order to access this encyclopedia.

E-Z Solve This is a powerful and easy-to-use equation-solving and graphing program. You can use it to solve a set of linear or nonlinear algebraic equations of the type you will encounter in almost every problem in Chapters 2-10 of the text. You can also use it to solve linear or nonlinear ordinary first-order differential equations of the type found in Chapter 11. The set of already solved examples is provided in the subfolder Examples, which you can access from the File|Open menu. Before you first attempt to use the program to solve a problem, you should click on Help on the menu bar and then on Tutorial on the pull-down menu that appears. Working through the tutorial is the easiest way to learn to use the application.

Physical Properties Database This section contains an on-line version of the physical property tables in Appendix B of the text. On the Physical Properties screen, you can look up any of the properties listed in Table B.1 of the text (molecular weight, specific gravity, etc.) for a specified species. On the Heat Capacities screen, you can find the heat capacity of a specified species at a specified temperature and 1 atm. You can also access a polynomial function for the heat capacity, like those listed in Table B.2 of the text, by copying the function name, pasting it into E-Z Solve, and entering a desired temperature as an argument. In the Steam Tables window, you can look up the specific volume, specific internal energy, and specific enthalpy of liquid water, saturated steam, or superheated steam at a specified temperature and pressure. You can also copy and paste the corresponding functions into E-Z Solve.

NAVIGATING ICPP

The installation creates icons in the Windows Start Menu and you can access any component from the Start Menu by clicking on the icons. The Main Menu that provides links to each component; this provides the easiest way to access each component of ICPP.

SYSTEM REQUIREMENTS

The software will run on Windows-compatible PCs, under Windows 95, 98, or NT 4.0. Recommended configuration is 486 DX 66, 16 MB RAM (64 MB RAM for NT), SVGA monitor (16-bit colors with 640x480 minimum resolution), 4X CD-ROM, video card, sound card, and speakers. A Web browser (Netscape Navigator 4.0 or Microsoft Internet Explorer 4.0) must be available to access the Index of Learning Styles component.

About 10 MB of free hard disk space will be required.

Installation instructions are printed on the CD.

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ATOMIC WEIGHTS AND NUMBERS

Atomic weights apply to naturally occurring isotopic compositions and are based on an atomic mass of $^{12}C = 12$

Element	Symbol	Atomic Number	Atomic Weight	Element	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	—	Iridium	Ir	77	192.2
Aluminum	Al	13	26.9815	Iron	Fe	26	55.847
Americium	Am	95	—	Krypton	Kr	36	83.80
Antimony	Sb	51	121.75	Lanthanum	La	57	138.91
Argon	Ar	18	39.948	Lawrencium	Lr	103	—
Arsenic	As	33	74.9216	Lead	Pb	82	207.19
Astatine	At	85	—	Lithium	Li	3	6.939
Barium	Ba	56	137.34	Lutetium	Lu	71	174.97
Berkelium	Bk	97	—	Magnesium	Mg	12	24.312
Beryllium	Be	4	9.0122	Manganese	Mn	25	54.9380
Bismuth	Bi	83	208.980	Mendelevium	Md	101	—
Boron	B	5	10.811	Mercury	Hg	80	200.59
Bromine	Br	35	79.904	Molybdenum	Mo	42	95.94
Cadmium	Cd	48	112.40	Neodymium	Nd	60	144.24
Calcium	Ca	20	40.08	Neon	Ne	10	20.183
Californium	Cf	98	—	Neptunium	Np	93	—
Carbon	C	6	12.01115	Nickel	Ni	28	58.71
Cerium	Ce	58	140.12	Niobium	Nb	41	92.906
Cesium	Cs	55	132.905	Nitrogen	N	7	14.0067
Chlorine	Cl	17	35.453	Nobelium	No	102	—
Chromium	Cr	24	51.996	Osmium	Os	75	190.2
Cobalt	Co	27	58.9332	Oxygen	O	8	15.9994
Copper	Cu	29	63.546	Palladium	Pd	46	106.4
Curium	Cm	96	—	Phosphorus	P	15	30.9738
Dysprosium	Dy	66	162.50	Platinum	Pt	78	195.09
Einsteinium	Es	99	—	Plutonium	Pu	94	—
Erbium	Er	68	167.26	Polonium	Po	84	—
Europium	Eu	63	151.96	Potassium	K	19	39.102
Fermium	Fm	100	—	Praseodymium	Pr	59	140.907
Fluorine	F	9	18.9984	Promethium	Pm	61	—
Francium	Fr	87	—	Protactinium	Pa	91	—
Gadolinium	Gd	64	157.25	Radium	Ra	88	—
Gallium	Ga	31	69.72	Radon	Rn	86	—
Germanium	Ge	32	72.59	Rhenium	Re	75	186.2
Gold	Au	79	196.967	Rhodium	Rh	45	102.905
Hafnium	Hf	72	178.49	Rubidium	Rb	37	84.57
Helium	He	2	4.0026	Ruthenium	Ru	44	101.07
Holmium	Ho	67	164.930	Samarium	Sm	62	150.35
Hydrogen	H	1	1.00797	Scandium	Sc	21	44.956
Indium	In	49	114.82	Selenium	Se	34	78.96
Iodine	I	53	126.9044	Silicon	Si	14	28.086

Atomic weights apply to naturally occurring isotopic compositions and are based on an atomic mass of $^{12}C = 12$

Element	Symbol	Atomic Number	Atomic Weight	Element	Symbol	Atomic Number	Atomic Weight
Silver	Ag	47	107.868	Tin	Sn	50	118.69
Sodium	Na	11	22.9898	Titanium	Ti	22	47.90
Strontium	Sr	38	87.62	Tungsten	W	74	183.85
Sulfur	S	16	32.064	Uranium	U	92	238.03
Tantalum	Ta	73	180.948	Vanadium	V	23	50.942
Technetium	Tc	43	—	Xenon	Xe	54	131.30
Tellurium	Te	52	127.60	Ytterbium	Yb	70	173.04
Terbium	Tb	65	158.924	Yttrium	Y	39	88.905
Thallium	Tl	81	204.37	Zinc	Zn	30	65.37
Thorium	Th	90	232.038	Zirconium	Zr	40	91.22
Thulium	Tm	69	168.934				

THE GAS CONSTANT

8.314 $m^3 \cdot Pa/(mol \cdot K)$

0.08314 L·bar/(mol·K)

0.08206 L·atm/(mol·K)

62.36 L·mm Hg/(mol·K)

0.7302 $ft^3 \cdot atm/(lb\text{-}mole \cdot °R)$

10.73 $ft^3 \cdot psia/(lb\text{-}mole \cdot °R)$

8.314 J/(mol·K)

1.987 cal/(mol·K)

1.987 Btu/(lb-mole·°R)

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